No. 13. JANUARY. 1907.

Bi-Monthly Bulletin

OF THE

American Institute of Mining Engineers.

PUBLISHED BY THE AMERICAN INSTITUTE OF MINING ENGINEERS

At S-W. Cor. Seventh and Cherry Sts.

PHILADELPHIA, PA.

EDITORIAL OFFICE AT 29 WEST 39TH STREET, NEW YORK, N. Y.

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SECTION I.

INSTITUTE ANNOUNCEMENTS.

This section contains announcements of general interest to the members of the Institute, but not always of sufficient permanent value to warrant republication in the volumes of the *Transactions.*

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* SECRETARY'S NOTE.—The Council is the professional body, having charge of the election of members, the holding of meetings (except business meetings), and the publication of papers, proceedings, etc. The Board of Directors is the body legally responsible for the business management of the Corporation, and is therefore, for convenience, composed of members residing in New York.

BI-MONTHLY BULLETIN.

For the convenience of persons who desire to file, or otherwise use separately, the technical papers in Section II. of the Bulletin, each of these papers has been paged and wired by itself; the whole collection being held together by a single, heavy wire, upon the removal of which it will fall apart into individual pamphlets, substantially like those formerly issued.

A small stock of separate pamphlets, duplicating the technical papers given in Section II. of this Bulletin, is reserved for those who desire extra copies of any single paper.

All communications concerning the contents of this Bulletin should be addressed to Dr. Joseph Struthers, Assistant Secretary and Editor, 29 W. 39th St., New York City (Telephone number 4600 Bryant).

SURPLUS PAMPHLETS ON HAND.

In taking account of stock, on the occasion of the recent removal of the office of the Institute, it was found that pamphlet copies of the papers named in the list given below were on hand, in excess of the average number deemed adequate for future casual demand. Special reduced rates will be made for these surplus copies to members applying promptly. "First come, first served."

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UNITED ENGINEERING SOCIETY BUILDING.

The Institute has occupied since Dec. 26, 1906, its offices in this building. All communications and other mail matter for the Institute or its officers should be addressed hereafter to "Engineering Society Building, 29 W. 39th Street, New York, N. Y."

The Institute library, however, was not removed with the executive offices, because the arrangements and furniture for its accommodation in the new building had not been completed, and it was consequently deemed advisable to keep the library at 99 John Street, where it could be daily consulted, as usual, by large numbers of engineers, rather than carry the books to a place where, for some time to come, they would have to be simply stored and guarded, without being available for use. This decision, involving the continued payment of rent for the rooms occupied by the library at 99 John Street, will doubtless be approved by members of the Institute.

A similar course was pursued by the American Society of Mechanical Engineers, of which the executive headquarters, but not the library, have been removed to the new building.

The American Institute of Electrical Engineers has postponed the removal of either its offices or its library, until both can be suitably installed.

The formal dedication of the building is expected to take place April 16, 1907, before which time it is earnestly hoped and confidently expected that all interior details will have been completed, and all departments of the three "Founder Societies" will have been transferred and installed.

The ceremonies and programme of this dedication are to be arranged by the Trustees of the United Engineering Society, the body incorporated by a special Act of the Legislature of the State of New York, to hold and administer the new building.

In accordance with the notice given in the Circular of January 19 from this office, a meeting of this Institute, for the reading and discussion of papers, will be held in New York City, immediately after the formal opening of the Engineering Building, in April. Further particulars as to all the above-named occasions will be given in later circulars.

LIBRARY.

Accessions.

From November 15, 1906, to January 15, 1907.

Alexander, L. H.

James Wilson, Patriot, and the Wilson Doctrine. 19 p. 8vo. n. p: n. d.

Theo. Audel & Company.

ROGERS, WILLIAM. *Pumps and Hydraulics.* 2 parts. 8vo. New York, 1905. Price, $4.00

[SECRETARY'S NOTE.—These two volumes contain a comprehensive collection of facts, rules, etc., somewhat miscellaneous in character and unequal in authoritative value, but abundant in quanity, and rendered useful to student and practitioner alike by ample indexes. While they cannot be said to constitute a systematic and logically arranged treatise, they present a wealth of practical information for which such a treatise might have no space. Such compilations are becoming more and more helpful to engineers as the enormous volume of technical literature increases. The contents comprise, among other things: a glossary of pump and hydraulic terms; descriptions, tables, etc., concerning turbines, hydraulic machinery, and all classes of pumps, air-compressors, fire-engines, injectors, and pulsometers; discussions of pumping-machinery for special purposes; and useful notes, formulas and tables almost innumerable. One of the most modern and valuable descriptions is that of the turbine-pump, which has recently attracted so much deserved attention from mining engineers, especially in its employment as a portable apparatus, run by electricity, and capable of unwatering a mine by simple suspension and lowering in the shaft. The first volume has, as a most appropriate frontispiece, the portrait of Henry Rossiter Worthington, one of the greatest of American inventors and hydraulic engineers.—R. W. R.]

William Cameron.

INDIAN TERRITORY—MINE INSPECTOR. *Report* for 1906. 8vo. Washington, 1906.

CARNEGIE, ANDREW. *Address by* . . . at the Presentation of Princeton Lake, Dec. 5, 1906. 8 p. 8vo. n. p: n. d.

——— *The Gospel of Wealth–II.* 13 p. 8vo. New York, n. d.

Wm. Bullock Clark.

MARYLAND GEOLOGICAL SURVEY. *Pleocene and Pleistocene.* 291 p. pl. maps. 4to. Baltimore, 1906.

F. L. Clerc.

CLERC. F. L. *Ore Deposits of the Joplin District.* p. 199–220. 8vo. Denver, 1906.

Commissioner of Lands and Mines, British Guiana.

BRITISH GUIANA—LAND AND MINES DEPARTMENT. *Report* for 1905–06. f°. Georgetown, Demerara, 1906.

Commissioner of Mines, Colony of Natal, S. Af.

SOUTH AFRICA—NATAL—MINES DEPARTMENT. *Report of the Mining Industry of Natal,* 1905. f°. Pietermaritzburg, 1906.

N. H. Darton.

DARTON, N. H. *Geology of the Owl Creek Mountains.* 48 p. 8vo. Washington, 1906.

Department of Mines, Queensland.

QUEENSLAND—GEOLOGICAL SURVEY. *Graphite in Queensland.* 20 p. 8vo.

——— ——— *Black Ridge, Clermont.* 141 p. pl. 8vo.

——— ——— *Oaks View Gold Mines.* 36 p. 8vo.

Dutch East Indies Government.

VERBEEK, R. D. M. *Description Géologique de l'Ile d'Ambon.* xxi, 1, 323 p. 8vo. Batavia, 1905.

——— Atlas.

Engineers' Society of Western Pennsylvania.

SOCIETY OF ARTS. *Journal.* Vols. 35, 37–43, 45, 47, 49, 51. 8vo. London, 1887–1903.

E. J. Ensign.

CALIFORNIA MINERS' ASSOCIATION. *Proceedings* of Fourteenth Annual Convention, 1905. 8vo. San Francisco, 1906.

General Electric Company.

GENERAL ELECTRIC COMPANY. *Catalogue of Railway Supplies.* 233 p. 4to. Schenectady, 1906.

Geological Survey of Canada.

CANADA—GEOLOGICAL SURVEY. *Annual Report*—Section of Mines. 1904. 8vo. Ottawa, 1906.

——— ——— SURVEY—LIBRARY. *Summary Report on the Operations of the Geological Survey for* 1886, 1888–89, 1892, 1893, 1894, 1901, 1902. 8vo. Montreal, 1887–1903.

Geological Survey of Ohio.

DERBY, A. G. A., and BROSSER, M. W. *Bibliography of Ohio Geology.* 332 p. 8vo. Columbus, 1906.

Professor U. S. Grant.

GRANT, U. S. *Structural Relations of the Wisconsin Zinc and Lead Deposits.* p. 233–42 il. 8vo. n.d, 1906.

———*Copper and Other Mineral Resources of Prince William Sound, Alaska.* p. 78–87 il. 8vo. n.d, 1906.

W. R. Ingalls.

INGALLS, W. R. *Lead Smelting and Refining, with some Notes on Lead Mining.* vii, 327 p. il. 8vo. New York–London, 1906. Price, $3.00.

[SECRETARY'S NOTE.—This is another book of the class already favorably known to readers of the *Engineering and Mining Journal*, namely,—reprints of articles which have appeared in that periodical, and which are later republished in volumes, finally revised, consecutively paged and provided with indexes. Apparently this practice is based on that of our Institute, which publishes its papers first in temporary and provisional form, and afterwards in permanent form, for convenient reference and study.

The present book comprises the subjects: lead mining in the U. S.; "roast-reaction" smelting processes, as practiced in reverberatories and Scotch hearths; the sintering and briquetting of slimes, fires, flue-dust, etc.; lead-smelting in blast-furnaces; the lime-roasting of galena; the Bormettes and Germot processes; flues, chambers and bag-houses for the recovery of dust and fumes; blowers and blowing-engines; and lead-refining by the Parkes method and by electrolytic methods. There are also accounts of lead-smelting in Spain and Sardinia, and descriptions of eight modern American plants. Metallurgists will not need to be informed of the value of such a series of up-to-date contributions to the literature of their profession.—R. W. R.]

A. C. Lane.

LANE, A. C. *Chemical Evolution of the Ocean.* p. 221–25. 8vo. n.d.

——— *Comment on the Report of the Special Committee on the Lake Superior Region.* p. 457–61. 8vo. n.d.

——— *Die Korngröse der Auvergnosen.* 19 p. il. pl. 8vo. Stuttgart, 1906.

——— *Interior of the Earth.* 2 p. 8vo. n.d.

——— *Natural Resources, Their Consumption and Conservation.* p. 17–26. 8vo. n.d.

——— *Possibility of Deep Cracks in the Earth.* 8 p. 12mo. n.d.

Library of the Great Britain Patent Office.

GREAT BRITAIN PATENT OFFICE—LIBRARY. *Key to the Classifications of the Patent Specifications of France, Germany, Austria, Norway, Denmark, Sweden and Switzerland,* in the Library of the Patent Office. Ed. 2. 208 p. 16mo. London, 1905.

W. F. Loring.

ZINC CORPORATION, LTD. *Report and Statement of Accounts,* 1906. Melbourne, 1906.

W. E. McCourt.

PARMELEE, C. W., and MCCOURT, W. E. *Report on the Peat Deposits of Northern New Jersey.* p. 223–313. 8vo. Trenton, 1906.

Oriental Consolidated Mining Company.

ORIENTAL CONSOLIDATED MINING COMPANY. *Report,* 1906. 4to. New York, 1906.

G. H. Perkins.

VERMONT—GEOLOGICAL SURVEY. *Report of the State Geologist on the Mineral Industries and Geology of Certain Areas.* 1905–06. 8vo. Montpelier, 1906.

T. A. Rickard.

MINING AND SCIENTIFIC PRESS. *After Earthquake and Fire.* 194 p. il. 8vo. San Francisco, 1906.

Professor Hjalmar Sjogren.

Jern Kontorets Annaler. Vol. 2, 4, 12–27 (inclusive). 8vo. Stockholm, 1818, 1820, 1829–45.

Staffordshire Iron and Steel Institute.

HIORNS, A. H. *Combined Influence of Certain Elements on Cast-Iron.* 12 p. pl. 8vo. Brierley-Hill, 1906.

Dr. Joseph Struthers.

TEES CONSERVANCY COMMISSIONERS. *Ports of the River Tees.* 39 p. il. pl. 8vo. n. p: n. d.

Tennessee Copper Company.

TENNESSEE COPPER COMPANY. *Report and Statements of Account,* 1905. Copperhill, 1905.

Transvaal Mines Department.

SOUTH AFRICA—TRANSVAAL. GEOLOGICAL SURVEY. *Report of the Survey,* 1905. f°. Pretoria, 1906.

U. S. Geological Survey.

U. S. GEOLOGICAL SURVEY. *Geologic Atlas of the United States, St. Marys Folio—Maryland-Virginia.* (Folio No. 136.)

——— *Dover Folio—Delaware-Maryland-New Jersey.* (Folio No. 137.)

——— *Redding Folio—California.* (Folio No 138.)

——— *Snoqualmie Folio—Washington.* (Folio No. 139.)

——— *Milwaukee Special Folio—Wisconsin.* (Folio No. 140.)

WEEKS, F. B. Bibliography and Index of North American Geology, etc., 1901–1905. 770 p. 8vo. Washington, 1906.

U. S. Geological Survey.

DARTON, N. H. *Geology of the Bighorn Mountains.* 4to. Washington, 1906. (Professional Paper No. 51.)

Dr. Hermann Wedding.

WEDDING, HERMANN. *Grundriss der Eisenhüttenkunde.* Ed. 5, xii, 392 p. 8vo. Berlin, 1906. (2 copies.)

———*Das Studium des Eisenhüttenwesens an der Königl.* Bergakademie in Berlin. 7 p. 8vo. Berlin, 1906.

Westinghouse Companies.

WESTINGHOUSE COMPANIES. *Exhibits* at the International Railway Congress, Washington, 1905. 46 p. il. 4to. New York, 1906.

Captain W. M. Wiley.

MARTIN, P. E. *Mexico's Treasure House* (*Guanajuato*). 259, ix p. pl. por. maps. 8vo. New York, 1906. An illustrated and descriptive account of the mines and their operations in 1906.

John Wiley & Sons.

IDDINGS, JOSEPH P. *Rock Minerals.* xii, 548 p. il. pl. 8vo. New York, 1906. Price, $5.00.

[SECRETARY'S NOTE.—Prof. Iddings is a recognized authority in the modern science of petrology, which has so greatly enlarged, and at the same time focalized and defined, the work of geologists. Neither the nature nor the history of a rock can be decided nowadays without recourse to the refined methods and trained judgment of the petrologist, to whom the field-observer habitually sends his specimens for examination and classification. This book supplies the pressing and general need of a clear, comprehensive and trustworthy manual of the new science. It treats of the general principles and methods of research, including the chemical and physical characters and laws involved, and gives (in Part II) a descriptive catalogue of the rock-making minerals, followed by tables showing their optical characteristics, and a large "folder," presenting a colored plate which exhibits their interference-colors and "birefringences." In short, the book is calculated to show the student how to observe thin sections of rocks, and how to interpret his observations—in both of which particulars there is danger of careless work and need of sane guidance.—R. W. R.]

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1902.	*William T. Batchelor,	September 27, 1906.
1900.	*R. G. Hart,	November 14, 1906.
1900.	*George L. Keener,	August 13, 1906.
1905.	*Frank C. Mandell,	December 14, 1906.
1895.	*Edmund H. Miller,	November 8, 1906.
1904.	*Arthur T. Rising,	October 10, 1906.
1896.	**John P. Wetherill,	November 9, 1906.

SECTION II.

TECHNICAL PAPERS AND DISCUSSIONS.

[The American Institute of Mining Engineers does not assume responsibility for any statement of fact or opinion advanced in its papers or discussions.]

A detailed list of the papers contained in this section is given in the Table of Contents, pages i and ii.

Comments or criticisms upon all papers given in this section, whether private corrections of typographical or other errors or communications for publication as "Discussions," or independent papers on the same or a related subject, are earnestly invited.

ERRATA.

Correction to *Bi-Monthly Bulletin*, No. 11, September, 1906.

Page.	
665	Table VII. For "0.80—0.10" read "0.80—1.00."

Corrections to *Bi-Monthly Bulletin*, No. 12, November, 1906.

Page.	Line.	
842	34	For "1875" read "1896."
853 858	10 and 11 45 and 46	For "William E. Kent" read "William Kent."
856		Add to list, the names Mrs. J. William Smith, Syracuse, N. Y.; Miss Agnes G. Smith, Syracuse, N. Y.; Miss Winifred A. Smith, Syracuse, N. Y.
858		Add to list, the names J. William Smith, Syracuse, N. Y.; Ernest Maxwell Smith, Syracuse, N. Y.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Cyanidation of Raw Pyritic Concentrates.

BY FRANK C. SMITH, WENDENDALE, ARIZ.

(London Meeting, July, 1906.)

THE following article covers the history of a metallurgical campaign, commenced in March, 1905, at the mines of the Socorro Gold Co., in the so-called desert region of Yuma county, Arizona. The results obtained were simply a function of necessity, as will be seen from the description of the local economic conditions and the character of the ores treated.

The mines and mill of the Socorro Gold Co. are located near the small village of Harrisburg, about 60 miles from Congress Junction, Arizona, which, at the time this work was undertaken, was the nearest railroad station, and from which all supplies were brought by wagon through the desert, at a cost varying from $10 to $15 per ton in addition to the railroad freights. Wood, the only available fuel, cost $7 per cord. Water for all purposes was pumped to the plant from a well in the valley about 4 miles away. Under the Arizona law, a working-shift is 8 hr. Wages were $6 per day for foremen and mill-men, $4 per day for blacksmiths and engineers, $3.50 per day for miners, and $3 per day for shovelers and trammers.

The ore consisted of quartz, in which, above the 250-ft. level, the iron-minerals were largely oxidized and some free gold was visible; below that level few traces of oxidation occurred, and pyrite constituted the principal mineralizer in the quartz, together with occasional pockets of galena and a few eccentric specks of covellite. The 20-stamp mill was equipped with plates for amalgamation, and three Standard tables for concentration. The tails from the tables were elevated by a centrifugal pump to a launder, by which they were conveyed to a 60-ton cyanide-mill for further treatment. The cyanide-mill was erected at so great a distance from the stamp-mill that a separate crew of workers and a separate power-plant were necessary. No arrangement had been made for the treatment of the concen-

trates as produced; although later, an adobe roasting-furnace had been erected near the stamp-mill, as well as a small cyanide-plant, for the treatment of the roasted product.

The treatment of the mill-tails in the remote cyanide-plant was unprofitable. The concentrates could not be shipped for treatment, on account of the high freight-cost and high smelter-charges; and, as the law of Arizona prohibited the use of wood as a fuel for roasting ore, the adobe furnace was useless. As a natural conclusion, it seemed evident that, if possible, an entire change of programme was necessary, involving two requisites: 1. A very clean concentration of the mill-tails, producing a final material containing very low values; 2. A local treatment of the raw concentrates.

The concentrating plant was unfitted to attain the first requisite; the Standard tables affording a very fair rough concentration, but making a very poor separation of middlings and slimes. Two Frue vanners were installed, the inefficient middling-pumps from the tables were thrown on the scrap-heap, and the plant started operation as follows: The tails from 10 stamps passed from the plates to one Standard table, and from this upon a second table. The tails from the other 10 stamps were similarly conducted upon a Standard table, but from this into a small spitzkasten, situated above the distributor of Frue vanner No. 1, from which the thickened pulp passed to the vanner for concentration, while the overflow passed to the slime-sump, mentioned later. The slimes from each of the tables were conducted by launder into a sump, from which they were elevated by a 2-in. Byron Jackson centrifugal pump into a set of 3 large spitzkastens arranged in a series, the overflow from the first passing into the second, etc., the final overflow, consisting of fairly clean water, passing into a supply-tank for use as feed-water for the batteries. The more or less de-watered slimes from the large spitzkastens were conducted by launders to a small spitzkasten, which discharged a product containing still less water upon Frue vanner No. 2 for concentration, the overflow from this last spitzkasten also passing back to the slime-sump. In the case of the first 10 stamps, the middlings from the first table passed with the tails to the second table, from which the final middling-product was caught in a separate receptacle and returned to the battery. The middlings

from the second 10 stamps passed with the tails from the table to the vanner. By this arrangement, only that water was wasted which was necessary to carry off the final tails and that which was necessary for the vanner-supply. It was found that the final tails were of very low grade; the result being somewhat surprising, considering the smallness of the concentration-plant for an output of 70 tons per day, but being doubtless referable to the comparatively simple character of the ore.

A futile attempt had formerly been made to extract the values of the table-concentrates by cyanidation without roasting, and about 60 tons remained in one of the cyanide tanks, from which a portion of the values had been extracted, but which yet contained about 6 oz. of silver and 2.25 oz. of gold per ton. An analysis of these concentrates suggested the following approximate constitution: SiO_2, 17.64; CaO, 4.95; FeS_2, 52.73; Fe_2O_3, 25.31; Pb, not det.; Cu, none; As, none; total, 100.63 per cent.

Continued leaching of these concentrates, for about 21 days, with solutions of various strengths, removed about 75 per cent. of the remaining values, but with a large consumption of cyanide, when the extraction practically ceased. The material was thoroughly aërated by turning over with shovels, and one-half placed in an adjoining tank: both portions were again subjected to leaching with cyanide, but with no compensatory extraction.

In the above treatment of the concentrates, the first solutions drawn off were of a brilliant claret color; and, as no copper had been found in the analysis, the reason for the phenomenon was somewhat obscure. A repeated test of the concentrates again showed no copper, but an analysis of the material, precipitated from the colored solution by addition of acid, proved it to consist of cupric ferro-cyanide. Further consideration discovered the source of the copper in the residue left by evaporation in one of the solution-tanks; this had been taken up by the new solution and produced the color mentioned. Analysis of samples of freshly-made concentrates showed them to contain about 0.2 per cent. of copper; enough to assist nicely in the zinc-precipitation.

After various experiments upon the raw concentrates, it was found that if the material was ground to 100-mesh and agitated

for 32 hr., about 85 per cent. of the gold and 70 per cent. of the silver could be extracted, at an expense of about 6.5 lb. of cyanide per ton. This result promised a very fair return (especially in a case where no other procedure was available); and the system was put in effect in the mill, with the happy, and somewhat unusual, result that the mill-practice has yielded very much better returns than those obtained in the laboratory-experiments; a fact which is probably due to the rise in temperature produced during the grinding of the pulp.

The yield of concentrates from the mill was about 2 tons per day. For grinding so small a product, the purchase of a ball- or tube-mill was out of the question; so also was the use of one of the stamp-batteries for the purpose; and about the least expensive machine which could be thought of, which would have a sufficient capacity and which would probably fulfill the other requirements, was one of the old-style amalgamating pans, such as are used in silver-mills. A second-hand, 5-ft. pan, with wooden sides, was bought in Denver, installed in the mill, and arranged to discharge into each of two leaching-tanks belonging to the small cyanide-plant formerly mentioned. The pan was charged with about one ton of solution carrying 6 lb. of cyanide, 6 lb. of lime and 1.5 tons of raw concentrates; it was set in motion at the rate of about 75 rev. per min., and continued to grind for 8.5 hr.; about 2 lb. more of cyanide being added during the day, as the strength failed. At the end of the period, the material was found to be finely ground, and was discharged into the leaching-tank; it was also found that, at the close of the grinding, the temperature of the mass had risen about 40° F. above the outside temperature. A sample of the ground pulp was taken, filtered, washed and assayed, with the somewhat surprising result that an extraction was shown of 90.7 per cent. of the values.

Since the initial test, the operation has been carried on continuously with similar results; the only variation occurring when the grinding was affected by the clogging of the mullers by foreign matter. Since this occurrence, the concentrates have been passed through an 8-mesh screen, and no further difficulty has been noticed. After the grinder is discharged into the leaching-tank, and after the solution has settled to some extent, it is customary to cover the material in the tank

with dry middlings from the table, for the purpose of facilitating percolation; in this manner, filtration goes on with sufficient rapidity. When one leaching-tank is filled, it is continuously leached with cyanide solution, while the other tank is being filled; it is then washed and discharged through a bottom-discharge door. The capacity of each tank is about 15 tons; so that a tank has about 4 days of extra leaching after it is filled; it then has 3 days' washing before discharge. During a campaign of 6 months, in which time various grades of concentrates have been treated, the average extraction has been about 94 per cent. of the total values. The grinding and cyanide-plant require little attention, except in the matter of charging the grinder and discharging it, and the whole plant is easily operated, without additional cost, by the man who has charge of the tables and vanners. The pan consumes about 8 h.p., and, as stated, the total cyanide consumption is about 8 lb. per ton; adding the cost of 6 lb. of lime, the total cost of the treatment of the concentrates, including the values left in the tails, does not materially exceed $5 per ton.

The concentrates, as they are taken from the tables and vanners, are given as much chance as possible to aërate and oxidize, since it is found to be the case that partly oxidized material grinds more quickly and gives up its values with a notably less amount of cyanide. In the extraction of the final values from the old concentrates upon which tests were first made, it is found necessary to grind them for 2.5 hr. only. Muller-shoes last about 3 months; while the dies last much longer. The zinc-precipitation is good, and the solutions have not yet become too foul for use; most of the copper is slagged off in remelting the bullion.

In the first attempts at the use of the grinding-pan, it was the intention to make the pan work continuously, by overflowing and allowing the continual discharge of finely-ground ore-particles into the leaching-tank. It was found, however, that the rapid motion of the mullers carried coarse as well as fine to the surface, and the scheme was abandoned. It was next attempted to allow a continuous discharge through pipes set midway up the sides of the pan, sizing with cyanide solution by *spitzlutten*, and return of the coarse material to the grinder. This also was abandoned, and the discharge-opening at the

bottom of the pan was threaded and a valve put in. The charge in the pan is now ground, the valve connected with a discharge-pipe, valve then opened and the contents of the pan discharged.

To show the grinding-efficiency of the pan, a series of sizing-tests were made upon concentrates as they came from the tables, and upon similar material after having been ground for 8 hr., as follows:

	Passed Through 100-mesh. Per Cent.	Passed Through 80-mesh. Per Cent.	Passed Through 60-mesh. Per Cent.	Coarser than 60-mesh. Per Cent.
Unground concentrates, . . .	51.08	14.7	6.20	28.02
Ground concentrates, ...	82.73	9.20	4.47	3.60

In crushing to the above degree of fineness, the material seemed to be fairly amenable to cyanidation, while not too fine for good filtration; so that 8-hr. grinding is continued.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Relative Elimination of Iron, Sulphur, and Arsenic in Bessemerizing Copper-Mattes.

BY E. P. MATHEWSON, ANACONDA, MONT.

(New York Meeting, April, 1907.)

THE experiments described in this paper were made at the Washoe Reduction Works, Anaconda, Mont., for the purpose of determining the relative speed of elimination of the iron, sulphur and arsenic during the process of bessemerizing copper-mattes.

The samples were taken from a horizontal "barrel" converter, 8 ft. in diameter and 12 ft. 6 in. long, having an average charge of 9 tons of matte, and blown with a 16-lb. air-pressure. All samples were taken with the blast on, turning the converter from its normal blowing-position to nearly vertical, so that a conical mold, with a long handle attached to a horizontal rod, could be introduced from a platform above the converter into the mouth of the converter and a sample taken. The difficulties of taking a sample with the blast on are apparent, and the irregularities of the lines in Figs. 1, 2 and 3 can be readily accounted for by the amount of slag in the samples. On the whole, the plotting of the results gives comparatively uniform lines, considering the conditions.

The samples were taken by the regular sampling-force of the works at 10-min. intervals, as shown in Tables I., II. and III., which also give the chemical analysis of the samples so taken. The test shown in Table I. was made with a new converter; that of Table II. with a converter that had made three charges and had been cleaned out; that of Table III. with a converter that had blown one charge to white metal, and had then been "washed" out and used for the test.

In plotting these results, it was necessary to take, as a basis, the percentage of copper in the samples. This basis does not exactly represent the true condition, since the volume is constantly decreasing and a certain quantity of copper passes into the slag, but it is as near as can be obtained in practice. Take, for instance, in Table I., the sample No. 5, which shows: Cu, 59.9;

TABLE I.—*Test with Stall No. 2, Converter No. 11, March 7, 1906.*

	Time.		Composition.						
	Hr.	Min.	Cu.	Au.	Ag.	Insol.	Fe.	S.	As.
			Per Cent.	Oz.	Oz.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
11.52 a.m., charged No. 1 blast matte			46.08	0.15	31.50	0.15	24.30	24.70	0.22
11.54 a.m., blow commenced.									
12.04 p.m., sample No. 1 blowing		10	46.02	0.17	31.80	1.30	23.70	22.95	0.07
12.14 p.m., sample No. 2 blowing		20	51.46	0.18	35.80	0.30	20.50	23.10	0.06
12.18 p.m., punched 3 min.									
12.24 p.m., sample No. 3 blowing		30	53.27	0.20	37.80	1.10	18.70	22.15	0.06
12.25 p.m., punched 7 min.									
12.34 p.m., sample No. 4 blowing		40	56.29	0.21	40.80	1.30	16.20	21.85	0.06
12.40 p.m., punched 2 min.									
12.44 p.m., sample No. 5 blowing		50	59.90	0.22	43.70	0.90	13.70	21.95	0.06
12.45 p.m., punched 2 min.									
12.54 p.m., sample No. 6 blowing	1	00	62.67	0.23	44.90	1.30	11.40	21.35	0.06
12.55 p.m., punched 6 min.									
1.04 p.m., sample No. 7 blowing	1	10	67.89	0.25	49.20	0.65	7.60	21.15	0.05
1.07 p.m., punched 3 min.									
1.12 p.m., blow stopped.									
1.13 p.m., skimmed.									
1.14 p.m., blow resumed.									
1.14 p.m., sample No. 8 blowing	1	20	73.97	0.27	54.90	0.25	3.40	20.10	0.05
1.17 p.m., punched 2 min.									
1.21 p.m., blow stopped.									
1.22 p.m., skimmed.									
1.25 p.m., blow resumed.									
1.25 p.m., sample No. 9 blowing	1	30	77.82	0.28	57.30	0.15	0.90	19.60	0.04
1.34 p.m., sample No. 10 blowing	1	40	74.16	0.26	54.30	3.30	2.60	16.60	0.04
1.44 p.m., sample No. 11 blowing	1	50	81.72	0.15	57.60	0.25	0.20	15.35	0.04
1.54 p.m., sample No. 12 blowing	2	00	98.50	0.78	107.70	0.017	trace	0.78	0.050
2.02 p.m., punched 1 min.									
2.04 p.m., sample No. 13 blowing	2	10	98.57	0.40	81.60	0.052	0.01	0.78	0.033
2.05 p.m., punched 2 min.									
2.08 p.m., blow stopped, test for Cu.									
2.09 p.m., blow resumed.									
2.10 p.m., blow finished.									
Converted copper	2	16	99.08	0.38	83.80	0.017	trace	0.01	0.033
Total time punching		28							
Total time of blow	2	16							
Actual time of blow	2	09							

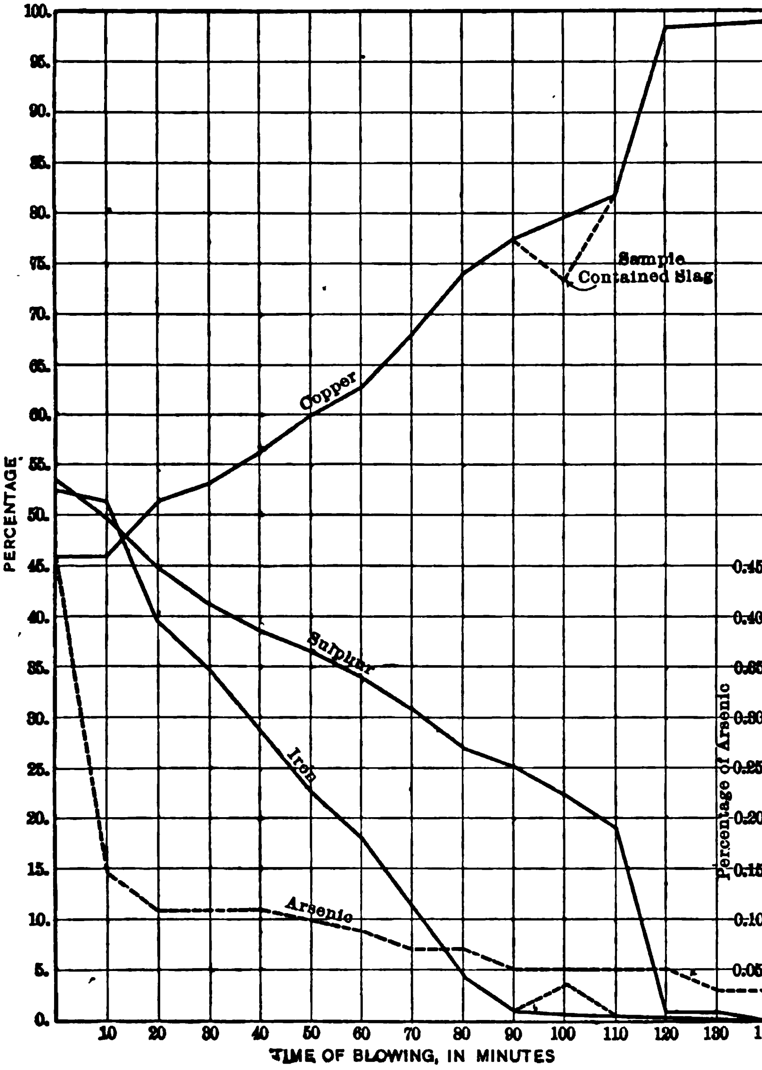

FIG. 1.—CHART OF TABLE I.

TABLE II.—*Test with Stall No.* 8, *Converter No.* 16, *April* 5, 1906.

	Time.		Composition.						
	Hr.	Min.	Cu.	Ag.	Au.	Insol.	Fe.	S.	As.
			Per Cent.	Oz.	Oz.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
2.22 p.m., charged Nos. 1 and 2 blast matte	....	....	54.81	39.30	0.17	0.30	18.00	23.00	0.076
2.28 p.m., started to blow.									
2.38 p.m., sample No. 1 blowing	....	10	56.26	39.80	0.17	0.44	17.40	20.30	0.065
2.48 p.m., sample No. 2 blowing	....	20	58.25	26.90	0.13	4.04	30.10	14.20	0.042
2.58 p.m., sample No. 3 blowing	....	30	64.71	46.50	0.22	0.80	10.40	20.10	0.040
3.08 p.m., sample No. 4 blowing	....	40	68.86	49.90	0.23	0.68	7.40	19.50	0.040
3.18 p.m., sample No. 5 blowing	....	50	72.72	53.40	0.24	0.28	4.20	18.20	0.042
3.19 p.m., stopped blowing 3 min. to skim.									
3.22 p.m., blowing resumed.									
3.28 p.m., sample No. 6 blowing	1	00	78.29	57.50	0.27	0.56	1.60	19.50	0.042
3.28 p.m., stopped blowing, skimmed 2 min.									
3.30 p.m., blowing resumed.									
3.38 p.m., sample No. 7 blowing	1	10	79.49	58.90	0.28	0.36	0.50	18.60	0.042
3.48 p.m., sample No. 8 blowing	1	20	78.27	55.90	0.30	2.04	0.90	16.40	0.042
3.58 p.m., sample No. 9 blowing	1	30	79.63	52.70	0.10	2.80	1.00	14.90	0.042
4.08 p.m., sample No. 10 blowing	1	40	82.85	49.50	0.12	1.34	0.80	13.10	0.034
4.18 p.m., sample No. 11 blowing	1	50	98.46	90.50	0.54	0.058	0.019	0.73	0.053
4.28 p.m., sample No. 12 blowing	2	0	98.75	76.30	0.37	0.020	0.012	0.53	0.049
4.32 p.m., blow finished, copper	....	....	99.26	85.70	0.37	0.022	0.004	trace	0.052
Gross time	2	02	....	....	....	....	....	....	....
Net time	1	57	....	....	....	....	....	....	....

No punching on this charge. Sample taken each ten minutes from beginning of blow until finished.

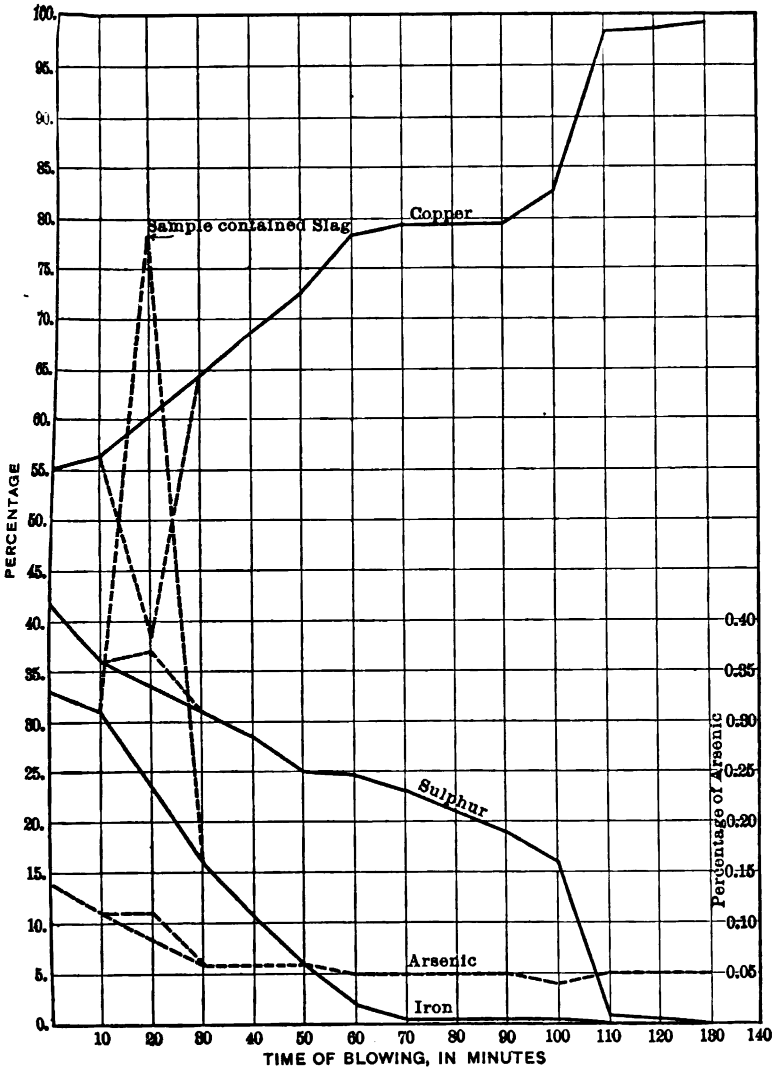

FIG. 2.—CHART OF TABLE II.

TABLE III.—*Test with Stall No. 2, Converter No. 3, April 12, 1906.*

	Time.		Composition.						
	Hr.	Min.	Cu.	Au.	Ag.	Insol.	Fe.	S.	As.
			Per Cent.	Oz.	Oz.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
11.03 a.m., charged No. 3 blast matte	....	....	40.68	0.13	29.70	0.20	29.60	24.30	0.095
11.05 a.m., blow commenced.									
11.15 a.m., sample No. 1 blowing	....	10	41.11	0.13	28.10	0.26	29.10	23.50	0.061
11.25 a.m., sample No. 2 blowing	....	20	42.50	0.13	29.40	1.04	27.80	22.70	0.045
11.35 a.m., sample No. 3 blowing	....	30	49.16	0.17	36.20	0.82	23.70	22.60	0.034
11.45 a.m., sample No. 4 blowing	....	40	55.86	0.24	42.20	0.68	17.50	22.90	0.034
11.51 a.m., blow stopped, skimmed 2 min.									
11.53 a.m., blow resumed.									
11.55 a.m., sample No. 5 blowing	....	50	62.97	0.30	47.00	0.62	12.10	20.40	0.034
12.05 p.m., sample No. 6 blowing	1	....	72.06	0.38	53.80	0.52	5.30	19.10	0.034
12.11 p.m., blow stopped, skimmed 3 min.									
12.14 p.m., blow resumed.									
12.15 p.m., sample No. 7 blowing	1	10	78.96	0.44	61.60	0.30	0.90	18.70	0.034
12.20 p.m., punched 1 min									
12.23 p.m., punched 1 min.									
12.25 p.m., sample No. 8 blowing	1	20	81.32	0.48	61.60	0.58	0.40	15.90	0.032
12.35 p.m., sample No. 9 blowing	1	30	98.24	1.46	114.00	0.022	0.011	0.81	0.088
12.45 p.m., sample No. 10 blowing	1	40	98.56	0.72	91.60	0.043	0.008	0.86	0.058
12.46 p.m., punched 9 min.									
12.55 p.m., blow finished, copper	1	50	99.17	0.60	88.50	0.025	trace	0.002	0.043
Actual time blowing	1	45	....	....	....	....	....	....	....
Gross time blowing	1	50	....	....	....	....	....	....	....

Sample taken each ten minutes from beginning of blow until finished.

[6]

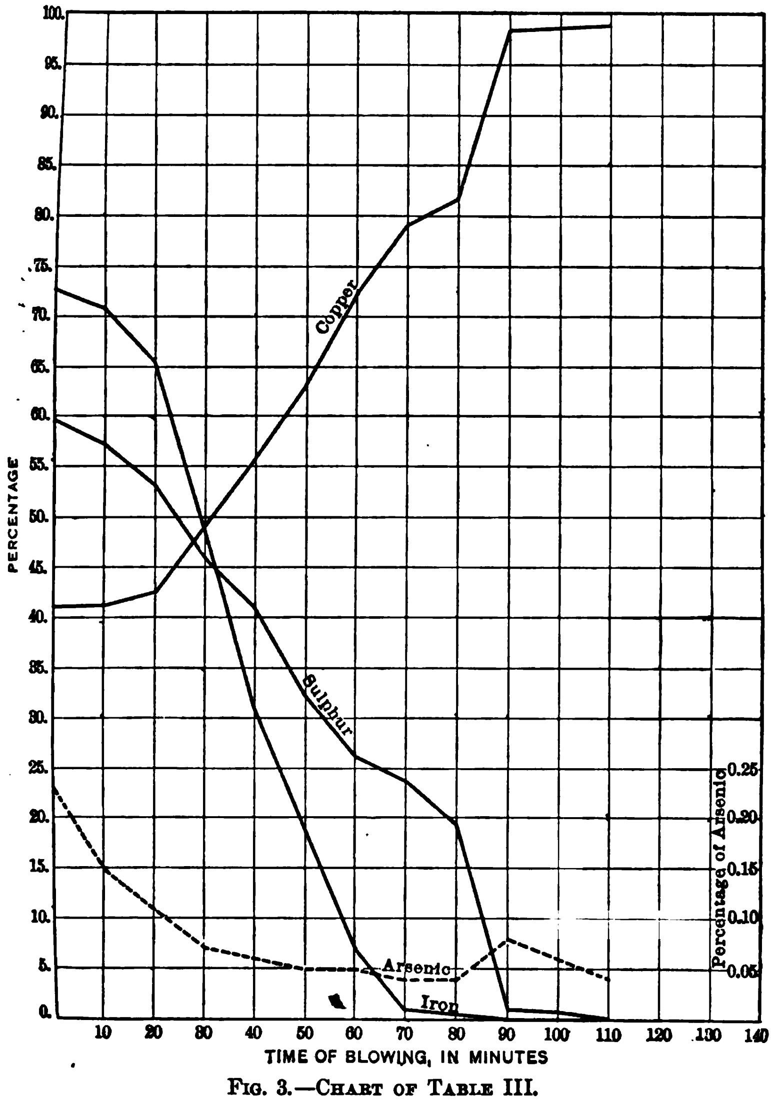

FIG. 3.—CHART OF TABLE III.

Fe, 13.7; S, 21.95 per cent., by actual analysis; then the plotted percentages are the percentages that 13.7 and 21.95 per cent. are of 59.9 per cent.; or 22.87 and 36.64 per cent., respectively. In the charts it will be noticed that the 10-min. intervals are plotted as the abscissæ, and the percentages of Cu, Fe, S, in 5-per cent. intervals, and arsenic in 0.05-per cent. intervals as the ordinates.

Table IV. shows the percentages of iron and sulphur volatilized during the first period, or to that point immediately after the last skimming.

TABLE IV.—*Quantities of Iron and Sulphur Volatilized in Bessemerizing Copper-Mattes.*

Test.	Copper in Matte. Per Cent.	Iron Eliminated. in First Period. Per Cent.	Sulphur Eliminated in First Period. Per Cent.
April 12, 1906, . . .	40.68	98	60
March 7, 1906, . . .	46.08	96	53
April 5, 1906, . . .	54.81	97	44

Apparently the major portion of the arsenic that is eliminated is driven off during the first 30 minutes.

The analyses of these samples were made by the regular force under the supervision of Mr. H. N. Thomson, chief chemist; the plotting by Mr. H. R. Burg, statistician, and the compilation by William Wraith, assistant superintendent, all of the Washoe Reduction Works.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Geology of the Exposed Treasure Lode, Mojave, California.

BY COURTENAY DE KALB, LOS ANGELES, CAL.

(New York Meeting, April, 1907.)

THE Exposed Treasure gold-mine has, for the past four years, been one of the largest producing mines of Southern California, its annual output having constituted 1 per cent. of the total gold and silver production of the entire State. At the present moment the property is idle, owing to the large quantity of water encountered on the lower levels, which will require the installation of a powerful pumping-plant before operations can be recommenced. Moreover, a prompt change in the character of the ore has occurred at water-level, which makes imperative an extensive campaign of development in the region of the unoxidized ores before a plant adapted to their treatment can be definitely decided upon.

The character of the changes encountered in these deeper ores makes the geology of this deposit a matter of importance, not only for the immediate district, but for the desert region of Southern California in general, where many mines exist having in the oxidized belt conditions that, in many respects, resemble those in the Exposed Treasure mine.

The deposit is situated in an apparently isolated butte about 2.5 miles south from the town of Mojave, on the Mojave desert. The butte, though apparently isolated, is in fact geologically part of an extinct volcano, known as Soledad butte, which rises out of the plain 1.5 miles SW. of the mine, to an altitude of 4,650 ft. above sea-level. Other buttes also rise from the desert plain toward the south and east, and again to the westward, all being closely related geologically to Soledad butte,—the whole constituting a single system as to origin and time. Since the end of the period of active volcanism in this region, there has been extensive denudation, the ancient plateau having been dissected during an epoch of apparently exces-

sive precipitation. The plateau is known, through well-borings in the gravel-fill of the desert, to have been cut down to a depth of 1,600 ft. below the present general level of the desert, and a reconstruction of Soledad butte from the angle of rest for lapilli, deduced from remnants of the ancient ash-cone still remaining, shows that it may have towered to a height 2,500 ft. greater than it now possesses. Other evidences of great activity in denudation on the Exposed Treasure butte are quite in accord with this estimate for Soledad.

Fig. 1 is a map of a part of the Mojave desert and the Tehachapi mountains,—Soledad butte being shown near the center.

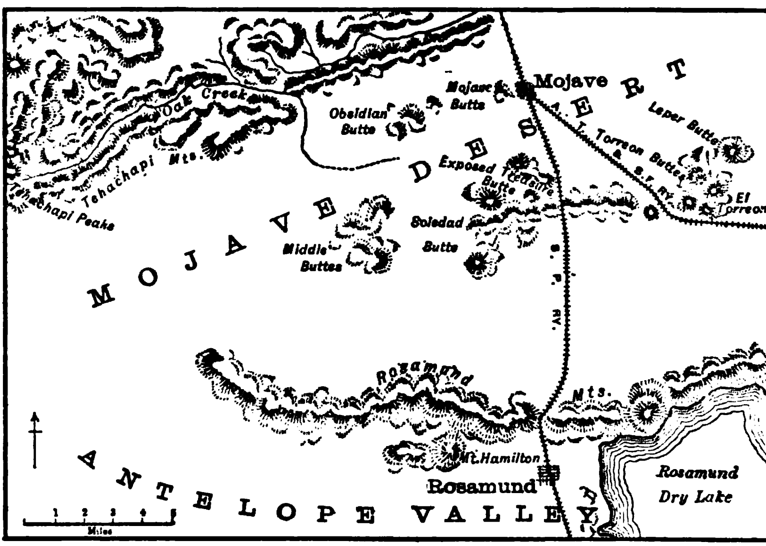

FIG. 1.—MAP OF A PORTION OF THE MOJAVE DESERT REGION, SOUTHERN CALIFORNIA.

The floor of the plateau consists of typical granite, extending to an unknown depth; and, being identical with the granite in the Tehachapi mountains, 5 miles to the northward, it is presumable that we have here the granites underlying the Tertiary sedimentaries, which still constitute the characteristic feature of the Tehachapi mountains in their eastward extension from the line of the Southern Pacific railway, although all traces of such sedimentary rocks are wanting toward the west, where this range culminates in the tripartite Tehachapi peak, 8,052 ft. high.

The granite itself has been invaded by extensive pegmatite

flows, determining the position of a low range of hills, which—for want of a name—I have for convenience called the Rosamund mountains. Pegmatite dikes also exist on the Exposed Treasure butte, and on the Torreon group of buttes, 5 miles to the eastward. As the Torreon group is connected with Soledad by a practically continuous chain of low hills, all lithologically related to Soledad, it may be fairly assumed that the original lines of weakness, contributing as one cause to the subsequent volcanic eruptions in the district, were those established by the pegmatite flows from the lower portions of the old granitic magma. It is worthy of note that these pegmatite dikes rarely show, by samples taken at random, a value in gold lower than 20c. per ton, and many of them, particularly in the Rosamund mountains, often assay as high as $1 per ton. The granite itself is never barren, but seldom carries more than 0.001 oz. of gold per ton. The absolutely universal dissemination of gold throughout all rocks in the entire district, requiring no refined methods of analysis to determine its presence, is a noteworthy circumstance.

The great mass of Soledad butte, as well as of its outlying hills, some of which were solfataras of the central volcano, consists of intensely acidic rhyolite-porphyry. Extensive fissuring has occurred in every direction, and all fissure-planes and zones have been further silicified, with abstraction of the alkaline feldspars, resulting in rocks often superficially resembling quartzite, sometimes possessing a porcelain-like texture, and a quality of resonance which has led to their being locally called phonolite. The fissuring has mostly occurred under slowly applied pressure, which has induced flowage of the porphyry, and even has caused it to become intrusive as dikes through the upper portions of the parent-rock. The flow-lines developed in the massive porphyry often give the rock the appearance of being contorted slates, while, on the other hand, the flow-dikes possess a granitoid structure which, on field-examination, would lead to their being presumptively identified as quartz-diorite. Microscopic investigation, however, proves that these dikes are only crushed rhyolite-porphyry, squeezed into crevices in the surrounding mass of porphyry and adjacent granite. No granite exists on Soledad at a higher elevation than 600 ft. above the desert-level, but it shoulders upon the

neighboring buttes, and exists in isolated masses, these being remnants from the denudation that has almost obliterated all traces of the dikes of porphyry that must have extended upward through the uplifted granite.

In Fig. 2 the relation of the porphyry to the granite is clearly shown, the remnants at the points of deepest denudation on the mountain mass demonstrating the previous existence of

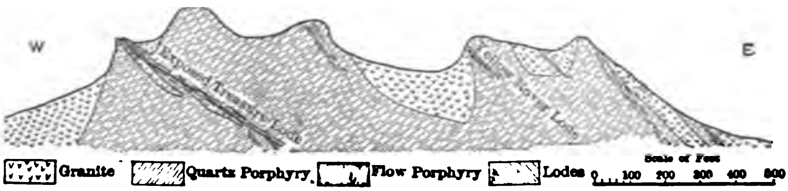

FIG. 2.—CROSS-SECTION OF EXPOSED TREASURE BUTTE.

large granite masses above. Fig. 3 is a sectional view showing the bottom of one of these wedges of granite in an adit tunnel on the Yellow Rover claim of the Exposed Treasure Mining Co. The fracturing of the lower point of the granite, and

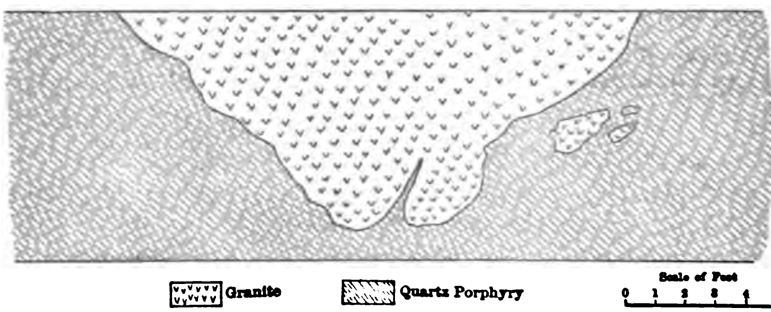

FIG. 3.—LOWER POINT OF GRANITE WEDGE UPLIFTED BY QUARTZ PORPHYRY.

near-by inclusions of granite in the rhyolite, are particularly interesting. Noteworthy, also, is the fact that no contact metamorphism has occurred, the granite being almost as fresh in contact with the porphyry as within the granite masses themselves. The rhyolite-porphyry on the Exposed Treasure butte, and on nearly all the hills surrounding Soledad, has evidently flowed into its present position in a pasty condition, and at no greatly elevated temperature. At the south-

eastern end of the Exposed Treasure butte, however, and at the volcanic stock constituting the Torreon, where solfataric phenomena were present, the porphyritic character of the eruptive disappears entirely; although in the center of the present porphyry dome on the Exposed Treasure butte the phenocrysts are splendidly developed, often attaining a major axis 1 in. in length, in a ground-mass which has undergone epidotization. In the mines in Soledad, where the porphyry has been revealed at considerable distances from the surface, the phenocrysts are not usually so well developed, and the ground-mass shows less alteration to epidote; it is also often quite fresh, and unchanged by the formation of secondary minerals, except in so far as silica has been introduced, as previously explained.

That Soledad was an active volcano is clearly proven by the important remnants of the ash-cone lying around the base of the mountain, notably abundant on the east side. There exists, moreover, on the west side of the mountain, a mass of volcanic tuff, buried under nearly 1,000 ft. of subsequent effusive rhyolite, the tuff having been compressed until it has developed horizontal cleavage, splitting the rock into layers of from 0.25 to 2 in. thick, as perfectly as the bedding-planes of a shale. This compressed tuff-remnant, 30 ft. in thickness, as revealed by denudation, makes it evident that there must have been at least two periods of volcanic outbursts connected with the effusion of the rhyolite alone.

The great acidic magma found its relief-vent chiefly at Soledad butte, but the uplift was general over a large area, and other vents existed at the Middle buttes, 4 miles west of Soledad; Mojave butte, now an inconspicuous hillock, where the rhyolite just emerges above the desert sands, 2.5 miles north of the Exposed Treasure butte; and Leper butte, a twin white shaft of quartz-porphyry standing solitary on the plain about 2 miles NE. from El Torreon,—the latter being the best type of volcanic stock in the district, though another fair example is found at the southeast end of the Exposed Treasure chain of buttes. The rhyolite also appears in the Rosamund mountains, and at Hamilton butte. My explorations in the Tehachapi mountains have failed to reveal any extension of the rhyolites into that range.

Subsequent to the rhyolite eruptions there was an outflow of andesites through extensive fissures in the Tehachapi mountains, forming one great system of dikes across the eastern edge of the Tehachapi plateau, and another 8 miles ENE. of the great Tehachapi peak. This outflow also reached the surface at Obsidian butte in the desert, and at one point on the ENE. flank of Soledad butte.

Three distinct periods of faulting are traceable in the Exposed Treasure butte, the first being a series of clean-cut fractures, approximately S. 80° E., with a maximum horizontal displacement of over 20 ft., and a vertical displacement of about 5 ft., the fissuring being unaccompanied by crushing or brecciation. One effect of this faulting was to oppose porphyry against granitic faces, thus disturbing the original relations of the dikes and the intercalated granite masses.

The second movement produced extensive rupture under shearing strains, resulting in excessive crushing of wide zones, traversing the rhyolites and granites indiscriminately, nearly at right angles to the direction of the earlier fault-planes. There are two related systems of shear-zones, one consisting of 9 parallel zones, each the *locus* of a vein, comprising also the Exposed Treasure vein, having an average course nearly due north and south, and splitting up into numerous branches in a NNW. direction, where they run into the other set of shear-zones, likewise palmate at the western end, where they merge into the related fault-system in the center of the great rhyolite boss constituting the mass of the Exposed Treasure butte. The course of this second set of shear-zones is S. 60° E., leading it directly into the solfataric stock at the southeast end of the ridge, where it again splits into numerous finger-like branches. It is, moreover, less continuous than the major system of shear-zones, and was seemingly caused by resultants of the original force, which met with a resistance in the homogeneous Exposed Treasure boss of rhyolite, producing a complicated branching of fractures. The north and south zones, therefore, may be spoken of as primary, and the NW–SE. zone as secondary. Magnificent grooving, like the best examples of glacial grooving to be seen in the north, occurs in many places on the foot-wall of the Exposed Treasure vein, in one stope an area of more than 100 by 300 ft. being furrowed into parallel

waves, some of which are 200 ft. long, 18 in. high, and approximately 3 ft. from crest to crest. These groovings bear N. 33° E., and dip 31° 15′ from the horizontal, while the dip of the foot-wall on which they occur is 34° 30′, N. 80° E. Closely corresponding evidences of the direction of movement are found throughout the mine, as deep as 800 ft. from the outcrop, and for over 1,000 ft. in length. The amount of throw or displacement has been measured with certainty at one point, from one original cross-fault, showing in the foot-wall, to its mate in the hanging-wall, revealing a total movement of the hanging-wall of 32 ft. toward the NNE. Similar evidences in the Yellow Rover and Boston mines, parallel with the Exposed Treasure mine on the east side, indicate that we here have shearing-zones accompanied by block-faulting on a large scale, the general movement being due to an approximately horizontal thrust coming from the direction of Soledad butte.

These parallel shear-zones, now converted into metalliferous lodes, with extensive chutes, and lenses of pay ore, all dip toward the east, those which outcrop at a considerable elevation having a steeper angle of dip (even as much as 60°) for a certain distance, then flattening rather abruptly to inclinations varying between 32° and 38°, gradually growing flatter in depth until, in the lower workings of the Exposed Treasure mine, the dip is only 27°. Furthermore, at the same absolute elevations, these parallel veins maintain identical dips, so that the parallelism is almost perfect throughout.

After this fissuring of the region, extensive silicification occurred, apparently unaccompanied by replacement. It was evidently a mere cementation of the crushed zones with silica, probably extruded from the cooling rhyolite mass in a colloidal condition, resulting in masses and infinitely ramified veinlets of chert, along with which was consolidated much FeS_2 as cubic pyrite. Kernels of this chert and its included breccia—the latter now consisting of granite and again of rhyolite, depending upon whether the fissure at that point was traversing one or the other of these two formations—are found frequently in both the Exposed Treasure and the Yellow Rover mines, and they rarely contain as much as 0.02 oz. of gold and 0.05 oz. of silver per ton, with complete absence of copper. This is universal throughout the mines of this group.

On practically all joint-planes throughout the unfaulted portion of the rhyolite boss (through the most highly porphyritic and unaltered portions equally with those where alteration has been profound), the same skeleton of cherty silica occurs, stained blackish-brown from iron oxides. On Soledad butte this extrusion of the overplus of magmatic silica is even more marked, but it contains a much smaller proportion of iron.

After this period of shear-faulting and subsequent cementation by silica, the veins or lodes were again subjected to faulting, in this case there being apparently no horizontal component, ordinary normal faults being produced. The effect was to re-brecciate the old cemented shear-zones. The formation of the metalliferous veins now commenced, the product being typical replacement-deposits. The silicates in the original breccia were, to a large extent, replaced by silica and metallic sulphides in the deeper portions, calcite becoming more abundant at higher levels until it finally became the predominant mineral, filling the interspaces between the cherty skeleton which had formed the cementing matrix of the earlier breccia. The calcite was of a liver-brown color, from mechanically contained manganese and iron compounds, and as the calcite in the upper portions of the veins dissolved away in advance of the denudation, the liberated manganese and iron oxides, together with clay, worked their way downward, so that in time great bodies of ore remained, consisting of a siliceous skeleton filled with a soft blackish-brown mixture of ferruginous clay and manganese dioxide, having much the appearance of an impure "bog" manganese. Throughout these masses were numerous blocks of the original cemented breccia, and the secondary breccia recemented with silica and calcite.

In the upper part of the veins, chrysocolla was a fairly common mineral, occurring both in the residual blocks of recemented breccia and lying detached in the soft manganiferous filling. It is also evident that the latest faulting had at places, temporarily at least, produced open fissures, as the occurrence of water-worn boulders, from the size of small pebbles up to 6 in. in diameter, would indicate. At one point in the Exposed Treasure vein, 40 ft. from the present outcrop, was a very remarkable mass of several tons of such surface *débris*,

cemented by calcite, while smaller pockets of such gravel, and isolated boulders, are common everywhere near the outcrop.

As stated before, while the lodes are continuous, and often of great width, sometimes being 40 ft. and more from wall to wall, the pay-streaks, from 4 to 15 ft. in width, lie in well-defined chutes and overlapping sheets or lenses. It is noteworthy that only those chutes or lenses which now reach the surface contained important quantities of calcite and manganese dioxide. In the deeper-seated lenses, which had no direct connection with the outcropping upper lenses, the absence of the above-named minerals is conspicuous, the ore here being entirely siliceous, except for residual blocks of the original breccia cemented by chert. The processes of decay, however, have extended also to these deeper-seated masses, the alteration consisting in sericitization and kaolinization, the latter applying chiefly to remnants of the old granitic breccia. The result has been to produce a semi-friable mass, including kernels and blocks of all sizes of the harder unaltered ore. Chrysocolla is also fairly abundant, and copper carbonate occurs universally, often in large amounts. The remnants of the earlier chert-filling, while frequently heavy with pyrite, contain no copper, but the residual masses of the unaltered secondary quartz always contained chalcopyrite in considerable quantities, along with marcasite, galena, and sphalerite. These kernels also presented another interesting phenomenon, illustrative of the processes of decay still going on. They were always surrounded by the friable sericitized ore, becoming "honey-combed" nearer the kernel, the latter being discolored by large amounts of the green copper carbonate, and even copper sulphate. Near the outer portion of the harder mass the chalcopyrite had been either converted into bornite or coated with a film of this mineral. Within the kernel the chalcopyrite remained unaltered. It appeared that during protracted epochs of drought, to which the desert is subject, the moisture had been withdrawn from these kernels by the combined action of evaporation and capillarity, the copper sulphate in part reacting with the chalcopyrite to produce bornite, and in part either crystallizing out on evaporation, or becoming partly converted into the carbonate. It was also uniformly found that such un-

altered copper-bearing kernels were richer in the precious metals than the altered friable ore. The altered ore bore manifest signs of extensive leaching, and where it had become almost completely decolorized by the removal of iron, the precious metal contents had nearly disappeared, and such ore never contained copper except in the form of chrysocolla.

The absence of sulphides in all the ores, except in the cherty skeletons, and in the undecomposed kernels of hard ore, was very complete. The mill-concentrates (150 into 1) had an average composition of SiO_2, 30; FeO, 37 (mostly from Fe_3O_4); and MnO_2, 12 per cent. These concentrates never contained more than 1.5 per cent. of sulphur.

In the lower friable siliceous ores, the ratio of gold to silver was as 1 to 12, while in the upper mangano-calcitic ores the ratio was as 1 to 72. Assays of gold-scale, and of coarse gold panned out, from all parts of the mine, showed a remarkably uniform alloy of 1 part of gold to 0.461 part of silver. The silver in the upper portion of the mine was present almost wholly in the form of silver chloride.

On the assumption, from the evidence, that the abundance of chlorides would prevent the leaching-out of the silver and its reconcentration below water-level, and that the ferric and cupric sulphates would have abstracted large quantities of the gold, which would be re-deposited lower down together with the copper in the form of secondary enrichments, it was natural to predict an ore below permanent water rich in these metals, and relatively lean in silver. It would be difficult to conceive a nicer justification of theory than that which was afforded when development at length extended below water-level. The ore consisted of a hard bluish-gray mass of original chert-cemented breccia, re-cemented by quartz, with partial replacement of the granite and quartz-porphyry by silica, heavily impregnated with sulphides, among which were considerable quantities of chalcopyrite, bornite, and some covellite. The gold-content of the ore had increased 150 per cent. above the average in the friable siliceous ores on the upper levels, and the ratio of the gold to silver was as 1 to 2.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Constitution of Ferro-Cuprous Sulphides.

BY H. O. HOFMAN, W. S. CAYPLESS AND E. E. HARRINGTON, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, BOSTON, MASS.

(New York Meeting, April, 1907.)

I. INTRODUCTION.

AT the Lake Superior meeting, September, 1904, Messrs. A. Gibb and R. C. Philp presented a paper entitled "The Constitution of Mattes Produced in Copper Smelting,"[1] in which they concluded that ferrous and cuprous sulphides formed the chemical compound, 5 Cu_2S, FeS. They arrived at this inference from the observed fact that a matte containing Cu_2S, 90.4, and FeS, 9.6 per cent. (or, in round figures, Cu_2S, 90, and FeS, 10 per cent.), did not contain any metallic copper, while one with more than 10 per cent. of FeS readily dissolved copper, and with less than this amount retained copper in mechanical suspension. Although they determined the melting-points of five mattes containing from 32.6 to 80.1 per cent. of copper, they did not draw a freezing-point curve, as the necessary apparatus was not available. A microscopical examination of 11 polished samples gave them a grayish-black field of very uniform appearance, except that 5 of the specimens showed the presence of metallic copper.

The object of the present investigation was to supplement the above paper by drawing the freezing-point curve of the series ferrous sulphide cuprous sulphide, and to see how the constitution could be further revealed by microscopical work. The results obtained lead to conclusions very different from those of Gibb and Philp. While their paper bears the date 1904, it was published only in 1906.[2] In the meantime, Bolles[3] had presented his paper, "The Concentration of Gold and Silver in Iron Bottoms." The raw material which formed the basis of the research was a matte containing Fe, 61.68, and Cu, 11.20

[1] *Trans.*, xxxvi., 665 to 680 (1906).

[2] *Trans.*, xxxvi., 665 (1906).

[3] *Trans.*, xxxv., 666 (1905).

per cent., produced by a smelting-plant, and therefore not pure; nevertheless, the microscopic results foreshadow some of the facts found in the present work.

II. Preparation of Ferrous and Cuprous Sulphides.

The two sulphides were prepared by heating metallic iron and copper with stick-sulphur. The apparatus, shown in Fig. 1, represents a vertical section through the pot-furnace used.

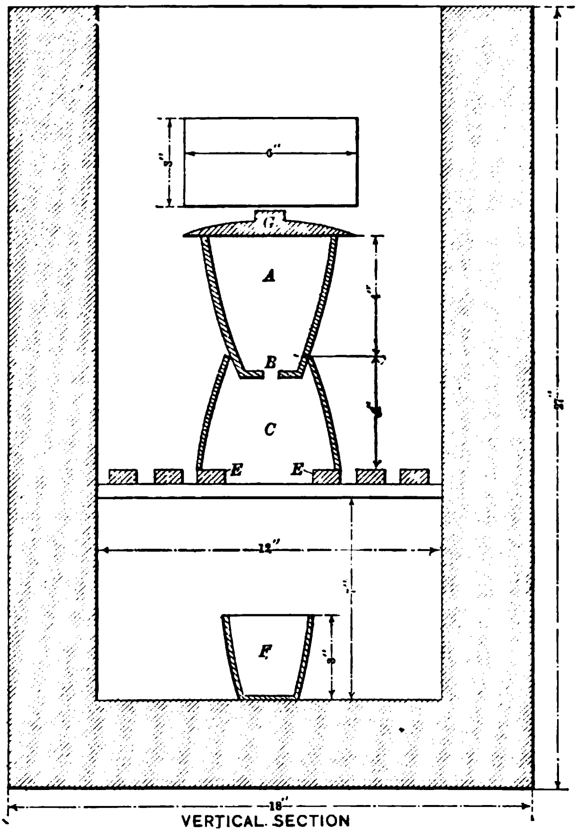

Fig. 1.—Pot Furnace.

This contains a No. K Hessian crucible, *A*, with a hole in the bottom, 0.5 in. in diameter, supported by a second crucible, *C*, of the same size, with bottom cut off for the length of 1 in. and inverted. The support rests upon grate-bars, *E*, which, keeping the coal and ashes away from the inclosed space, makes it possible to collect clean sulphide in the No. B. Denver crucible, *F*, placed in the ash-pit.

Soft iron wire, No. 14 B. & S. gauge, cut into 6-in. lengths, was placed in the perforated crucible. When this had been brought to an orange-red, the cover, *G*, was removed. From 10 to 15 g. of stick-sulphur was crushed to hazelnut-size, added, and the cover replaced. Iron and sulphur combined readily, and the iron sulphide, melting at a low temperature, flowed through the hole in the crucible and was caught in the receiver. When the flow of iron sulphide ceased, fresh additions of sulphur were made. If too much sulphur was added at one time, it simply ran out through the bottom of the crucible without uniting with the iron.

In order to obtain a uniform compound in which all the iron was combined with the sulphur, the first iron sulphide was broken into pieces of hazelnut-size and placed in a graphite crucible with additional sulphur; powdered charcoal was added and the crucible covered to exclude the air; and the charge heated in the pot-furnace until the sulphide had become entirely liquefied. The crucible was then removed and its content allowed to cool slowly. The chemical analysis gave Fe, 64.57 per cent., while FeS consists of Fe, 63.54, and S, 26.46 per cent. The excess of iron present is due to the fact observed by Le Chatelier and Ziegler,[4] that ferrous sulphide heated above its melting-point, air being excluded, loses sulphur, and that the loss in sulphur increases with the temperature. A photomicrograph is shown in Fig. 4. The ferrous sulphide was full of cavities and fissures, caused by evolution of gas and by shrinkage in cooling. It was therefore difficult to find parts giving a smooth surface for microscopical examination.

Pure copper wire, No. 15 B. & S. gauge, cut into 6-in. lengths, was treated in the same way as the iron. The temperature of the copper had to be higher than that of the iron for the sulphur to combine with it. The cake of re-melted sulphide showed, when broken, radial fracture-planes forming elongated particles with surfaces resembling hard specular iron-ore in color and luster. The chemical analysis gave Cu, 78.94 per cent., while the theoretical percentage of copper in cuprous sul-

[4] *Bulletin de la Société d'Encouragement pour l'Industrie Nationale*, ciii., p. 368 (1902); *Metallographist*, vol. vi., p. 19 (1903).

phide is 79.68. A photomicrograph of this sulphide is shown in Fig. 14.

III. Determination of the Freezing-Point Curve.

The apparatus used at first for fusing mixtures of ferrous and cuprous sulphides was an electric resistance furnace. It consisted of a porous fire-clay cup, 3.25 in. in diameter and 7 in. high, wound with 9 ft. of platinum wire of No. 26 B. & S. gauge, a cylinder of galvanized iron 10.5 in. in diameter and 12 in. high, and magnesia packing. The winding was calculated to give, with 8 amperes, a temperature of from 1,200° to 1,300° C. On account of the care and the long time (about 45 min.) it took to bring the furnace to the required temperatures, it was abandoned and replaced by a small No. 40 Fletcher gas-furnace, 5 in. in diameter, which was easily heated to 1,200° C. in 5 min. The rapid cooling characteristic of this type of furnace was obviated by enclosing it in a 1-in. covering of magnesia and using a cover of the same material with a hole in the center. The cooling was sufficiently slow to accentuate retardation-points of the fused mixtures held in No. 2 graphite crucibles.

Temperatures were measured with the Le Chatelier thermoelectric pyrometer. The wires were insulated from one another by a double-bored clay tube, and the hot-junction protected from the corrosive action of melted matte by a Berlin porcelain tube, 0.5 in. in diameter and 10 in. long, one end of which had been closed by fusing with an oxy-hydrogen gas blow-pipe. The current produced by heating the thermo-junction was measured with a Sullivan mirror galvanometer. The instrument was read by the movement of a reflected ray of light on a ground glass-plate, on the lower side of which a strip of millimeter plotting-paper had been pasted. On calibrating, the instrument gave, with the cold-junction at 28° C., a deflection of 280 mm. for the copper point and one of 160 mm. for the aluminum point, or 120 scale-divisions corresponded to 427° C., or 1 division to about 3.5° C. In Fig. 2, representing the arrangement of apparatus, *A* is a table; *B*, Fletcher furnace; *C*, stand; *D*, handle of pyrometer; *E*, cold-junction thermometer; *F*, Sullivan mirror galvanometer; *G*, pyra-

midal wooden hood (⅛-in. stock); *H*, incandescent electric lamp; *I* and *J*, supports.

The charges used at first weighed 20 g., but as these cooled too quickly, the quantity was doubled, which was found to be sufficient to mark distinctly the first retardations while cooling. In other experiments that are contemplated the weight of a charge will be increased to 100 g. to bring out more points for the freezing of the eutectic. In making up the charges, the necessary quantities of ferrous and cuprous sulphides were weighed out, sulphur was added, and the whole mixed and covered with a layer of fine charcoal.

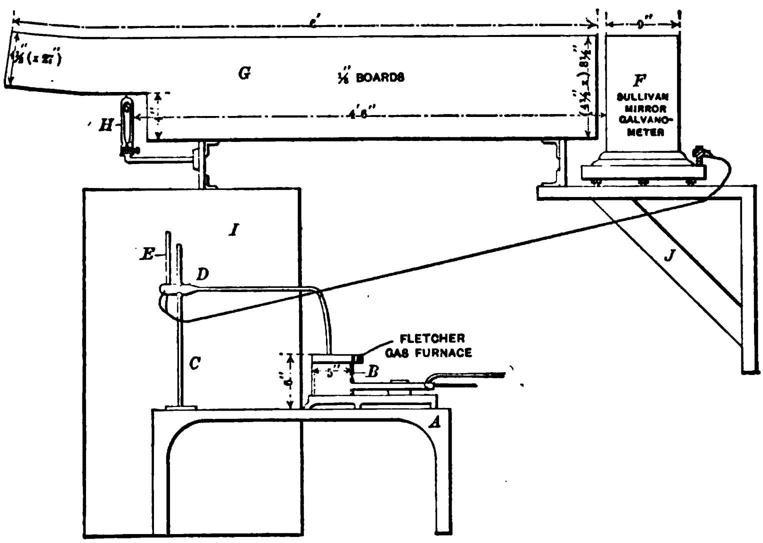

FIG. 2.—ARRANGEMENT OF MELTING-APPARATUS.

When a charge was fused, the heated porcelain protecting tube was inserted, to be followed by the thermocouple. When this indicated the temperature of fused mixture, the gas-burner was shut off and the crucible and content allowed to cool slowly in the usual way, i.e., without stirring the charge. Readings were taken by noting the time in seconds it took the ray of light to drop half a division on the scale. It was observed that when the gas-burner had been removed, the temperature continued to rise as much as 25° C. before it began to fall. Similarly, when heat was applied to acharge which had

been cooling, the cooling continued for some time before the temperature started again to rise.

In allowing the charge to cool without stirring, the retardations often covered quite a range of temperature and masked the real point of solidification. If the charge was stirred, it solidified more uniformly and gave a more marked freezing-point.

In samples of matte with high percentages of cuprous sulphide the solidification proceeded more quickly and satisfactorily than when the percentages of ferrous sulphide were high. The readings taken with stirring are recorded in Table I.:—

TABLE I.—*Record of Freezing-Points of Iron-Copper Sulphides.*

FeS.	Cu_2S.	Observed Retardations.
Per Cent.	Per Cent.	Degrees Centigrade.
100	0	978
95	5	920
90	10	884, 886
85	15	885
80	20	850, 858, 859, 859, 859, 879
75	25	855, 856
70	30	854, 858
65	35	850, 858, 860, 865
60	40	862, 913, 917, 919
50	50	978
40	60	1,028
30	70	1,053
20	80	1,090, 1,094
10	90	1,123, 1,126, 1,129
0	100	1,152

The retardation-points in matte sometimes show marked differences. This is probably due to the facts, 1, that a matte does not solidify as suddenly as does a metal or an alloy composed of metals; 2, that a porcelain tube is attacked by matte especially when rich in ferrous sulphide; 3, that matte has the property of dissolving small amounts of slag; and 4, that the limit of accuracy of a pyrometer-reading was 3.5° C. Second retardations in the mattes were noticed only three times: at 862° C., with the matte containing FeS, 60, and Cu_2S, 40 per cent.; at 850° C., with the matte containing FeS, 65, and Cu_2S, 35 per cent.; and FeS, 80, and Cu_2S, 20 per cent. The point 850° C. was sufficiently marked to accept this, at least provisionally, as the freezing-point of the eutectic. The freezing-point curve drawn in Fig. 3 has a V-form characteristic for

eutectiferous alloys. The sudden peculiar deflection of the curve from its general course between FeS, 60, and Cu_2S, 40 per cent., and FeS, 65, and Cu_2S, 35 per cent., seems to be borne out by the abrupt change of structure shown in the photomicrographs, Figs. 10 and 11. The ferrous-sulphide and cuprous-sulphide branches are drawn to meet at the point representing the composition, FeS, 86, and Cu_2S, 14 per cent., as the microscopical examination showed that the eutectic point lay a little beyond FeS, 85 per cent. Similar reasons justified dotting the eutectic line from FeS, 90 per cent., to the eutectic

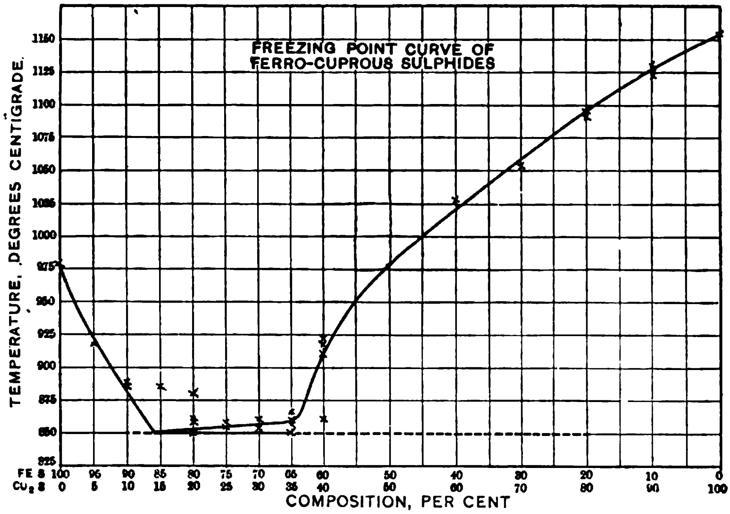

FIG. 3.—FREEZING-POINT CURVE OF FERRO-CUPROUS SULPHIDES.

point, and from FeS, 65, and Cu_2S, 35 per cent., to FeS, 20, and Cu_2S, 80 per cent.

IV. MICROSCOPICAL EXAMINATION.

The samples were polished on a Sauveur machine in the usual way with coarse and fine emery, and with rouge; the polished surfaces were then cleaned and burnished on a disk covered with wetted broadcloth. Samples rich in cuprous sulphide were easier to polish than those rich in ferrous sulphide, since the latter were filled with pits, which was not the case with the former. Attempts at etching a polished surface with silver nitrate to attack the cuprous sulphide, and with potassium-copper chloride to attack the ferrous sulphide did not help to develop

the structure; on the contrary, they blurred what was distinct before. The samples were therefore microphotographed without having been etched, but a deep-orange screen was used to furnish the desired contrast on the negative between the blue rays of cuprous sulphide, the fawn-colored rays of ferrous sulphide, and the purplish-drab of one component of the eutectic. The time of exposure to the 110-volt arc-light, using Cramer's instantaneous isochromatic plates, was 1.25 min. with samples containing Cu_2S, from 100 to 50 per cent., while 1.5 min. was found to be necessary with the others. The magnification throughout was 300 diameters.

1. *FeS,* 100, *and* Cu_2S, 0 *per cent.*, Fig. 4, shows two constituents, white areas of ferrous sulphide and a gray eutectic resembling the impression made by a thumb-print. Under the microscope ferrous sulphide is fawn-colored. The eutectic consists of plates of ferrous sulphide and a component of a purplish-drab color. The black spots are cavities. Le Chatelier and Ziegler[5] distinguished three constituents, yellow areas of ferrous sulphide, white brilliant particles of metallic iron, and a eutectic composed of yellow sulphide and a mixture of iron oxide and metallic iron, with the former strongly predominating. The white specks were not visible in our sample, and immersion in a cupric sulphate solution showed only here and there a slight tracery of metallic copper.

2. *FeS,* 95, *and* Cu_2S, 5 *Per Cent.*—The structure is the same as that of pure ferrous sulphide (Sample No. 1), with this difference, that the plates making up the eutectic are larger and slightly deeper in color.

3. *FeS,* 90, *and* Cu_2S, 10 *per cent.*, Fig. 5, shows the effect of a larger addition of cuprous sulphide which was to reduce in size the fawn-colored areas of ferrous sulphide and the purplish-drab colored eutectic. The excess-ferrous sulphide is more interwoven with the eutectic than before, and the cavities and fissures are also smaller in number and in size.

4. *FeS,* 85, *and* Cu_2S, 15 *per cent.*, Fig. 6, presents a general appearance which differs from that of Sample No. 3. Nearly the entire field is covered by the eutectic, showing the components as before; there is no indication of excess ferrous sul-

[5] *Bulletin de la Sociètiè d'Encouragement pour l'Industrie Nationale*, ciii., p. 368 (1902); *Metallographist*, vol. vi., p. 19 (1903).

FIG. 4.

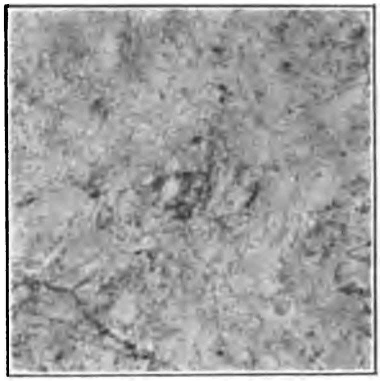

FIG. 5.

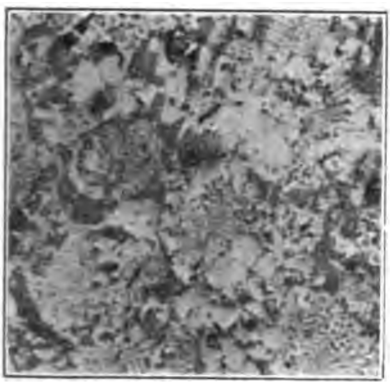

FIG. 6.

FIG. 7.

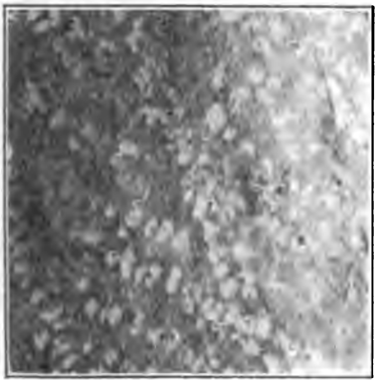

FIG. 8.

FIG. 9.

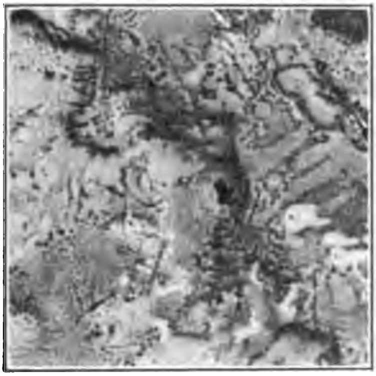

FIG. 10.

FIG. 11.

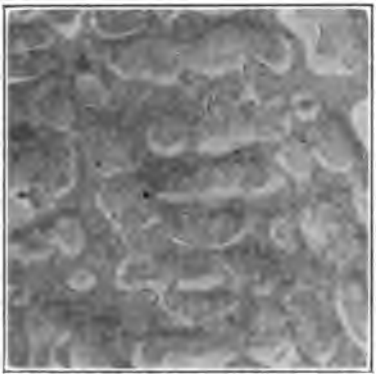

FIG. 12.

FIG. 13.

FIG. 14.

[10]

phide, which has disappeared in the eutectic. The dark members of the eutectic have become prominent, they are often bunched together, and show here and there a strawberry-like surface. For the first time there appear a few sky-blue areas of cuprous sulphide. In the print they are darker than the dark component of the eutectic, have no connection with it, and show no structure whatever. The appearance of sky-blue cuprous sulphide proves that the eutectic point of the alloy has been passed, but only slightly, as, with the exception of a few small areas, the whole field is made up of eutectic. This was the reason for drawing the ferrous- and cuprous-sulphide branches that they met at FeS, 86 per cent.

5. *FeS*, 80, *and* Cu_2S, 20 *per cent.*, Fig. 7, is the print made from the clearest negative that could be obtained from the sample which appeared hazy under the microscope. The sky-blue parts of cuprous sulphide, light-colored in the print, have become more numerous. The structure of the eutectic is fine; while obscured in the print, it is visible under the microscope.

6. *FeS*, 75, *and* Cu_2S, 25 *per cent.*, Fig. 8, the print of this sample resembles very much that of sample No. 5, the light-colored particles of cuprous sulphide are smaller, more numerous and better defined; the eutectic hardly reveals any structure.

7. *FeS*, 70, *and* Cu_2S, 30 *per cent.*, Fig. 9, shows that the microscopical aspect has completely changed. There is a sky-blue area of cuprous sulphide, with particles of a fawn to purplish-drab color disseminated through it; the eutectic islands are fawn-colored where the structure is indistinct, and a more purplish-drab where it is readily seen. Specks of metallic copper, white in the print, make their first appearance. The resulting enrichment of the matte in ferrous sulphide was not taken into account.

8. *FeS*, 65, *and* Cu_2S, 35 *per cent.*, Fig. 10, shows that the free development of components seems to have been hampered, which gives the photograph a different aspect from that of Sample No. 7, although the constituents remain the same. The dark structureless parts are cuprous sulphide; the eutectic structure is very marked; white particles of copper are less scarce and larger.

9. *FeS*, 60, *and* Cu_2S, 30 *per cent.*, Fig. 11, shows that the grouping of the constituent parts is different from any of those

of Samples Nos. 1 to 8. In the picture the dark knob-like structureless parts are sky-blue cuprous sulphide; these appear to be enclosed by light-colored rings, which seem to be surrounded by a dark mass showing here and there some structure. Under the microscope the blue is clearly the sea in which float eutectic fawn-colored islands, in the centers of which has been assembled the other constituent with its purplish-drab color. This sudden change of structure, shown in Figs. 10 and 11, denotes a decided change in the reciprocal solubility of the two sulphides, and is brought out clearly in the freezing-point curve.

10. *FeS*, 50, *and* Cu_2S, 50 *per cent.*, Fig. 12, has the same general character as Fig. 11; the constituents are, however, larger, and the purplish-drab component of the eutectic presents more structure.

11. *FeS*, 40, *and* Cu_2S, 60 *per cent.*, Fig. 13, presents a background of blue cuprous sulphide, having large and small eutectic islands of a fawn color, showing very little structure. The white patches are metallic copper, which reaches here its maximum and decreases quickly in the subsequent samples.

12. *FeS*, 30, *and* Cu_2S, 70 *Per Cent.*—The photograph of this material differs too little from that of Fig. 13 to warrant reproduction.

13. *FeS*, 20, *and* Cu_2S, 80 *per cent.; FeS*, 10, *and* Cu_2S, 90 *per cent.; FeS, and* Cu_2S, 100 *per cent.*, Fig. 14, shows that all these samples have a plain blue field without any structure whatever; all contain small particles of metallic copper. This disappearance of all structure with the composition, FeS, 20, and Cu_2S, 80 per cent., justifies drawing the eutectic line up to this point.

V. Conclusion.

In summarizing the results, the conclusions arrived at are:

1. Ferrous and cuprous sulphides form no chemical but a eutectiferous compound.

2. The structure of the eutectic of ferrous and cuprous sulphides becomes merged in that of the pure ferrous sulphide and cannot be distinguished from it.

3. The limited reciprocal solubility of the two sulphides diminishes along the cuprous-sulphide branch of the curve, slowly at first, then more quickly; solubility is complete beyond the alloy, FeS, 20, and Cu_2S, 80 per cent.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Laboratory Experiments in Lime-Roasting a Galena Concentrate with Reference to the Savelsberg Process.

BY H. O. HOFMAN, R. P. REYNOLDS AND A. E. WELLS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, BOSTON, MASS.

(New York Meeting, April, 1907.)*

I. INTRODUCTION.

LIME-ROASTING is a term proposed by Ingalls[1] for the operation of forcing air under pressure through a mixture of galena and lime at the kindling-temperature with the object of oxidizing lead and sulphur and of fritting or fusing the charge. If finely-divided galena were treated in this manner without the addition of lime, the heat set free by the oxidation of part of the lead and the sulphur would be sufficiently great to fuse undecomposed sulphide, and thus stop desulphurization. Besides the chemical action that the addition of lime, limestone or gypsum to the charge may have, the admixture has the physical effect that it keeps the particles of galena separated from one another and accessible to the oxidizing effect of the air.

At present, three methods of lime-roasting are carried out on a working-scale,—the Huntington-Heberlein, the Carmichael-Bradford and the Savelsberg[2] processes. In the last, which interests us here, an 8-ton charge is made up of galena, limestone and perhaps some siliceous or ferruginous flux; the whole is crushed to pass a screen with 3-mm. holes and moistened with 5 per cent. of water. It is fed gradually into a bowl-shaped converter, 6.56 ft. in diameter, supported by trunnions attached to a truck. On the bottom the converter has a grate with blast-inlet beneath. In starting, the truck with the converter

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* Read by title at the London Meeting, July, 1906. Manuscript received Aug. 23, 1906.

[1] *Engineering and Mining Journal*, vol. lxxx., p. 402 (1905).

[2] United States Patent, No. 755,598, March 22, 1904. *Engineering and Mining Journal*, vol. lxxx., p. 1067 (1905) (Ingalls); vol. lxxxi., p. 9 (1906). *Mining Magazine*, vol. xii., p. 391 (1905) (Savelsberg). *The Mineral Industry*, vol. xiv., p. 407 (1905) (Hofman).

is run underneath a stationary hood, which carries off the gases and fumes; the grate is covered with a layer of crushed limestone for the sake of protection; then follows a bed of glowing coal or coke, to be covered by a second layer of limestone to prevent contact of fuel and charge. A gentle blast is turned on and charge fed in to the depth of 12 in. Oxidation begins at the bottom and sulphurous gases are given off; when the roasting approaches the surface and this becomes red-hot, a second layer of charge is fed in, and feeding continued at intervals until the converter has been filled. While charging, about 247 cu. ft. of air is forced in with a pressure ranging at the start from 2.75 to 4.5 oz. per sq. in.; the volume of air is increased with the amount of charge fed, and this causes the pressure to rise to from 11.5 to 13.5 oz. per sq. in. toward the end of the blow, lasting about 18 hours. Desulphurization is followed closely by scorification and this by solidification. The charge does not become liquid as a whole, as the formation of the slag is a heat-absorbing reaction and as the blast chills the slag. The converter, when blown, is withdrawn on its truck from beneath the hood; the charge is dumped onto an upright iron bar to break it into several pieces, which are then further reduced in size by wedging and sledging. A typical charge at Ramsbeck, Westphalia, with 100 parts of galena concentrate (Pb, from 60 to 78; S, 15 per cent.), 10 siliceous silver-ore, 10 spathic iron-ore and 19 limestone, averaging SiO_2, 11 per cent., will retain from 2 to 3 per cent. of S when successfully blown.

The literature of the process gives very little information upon the effects which variations in the addition of limestone and changes in the volume of blast may exert upon desulphurization, fusibility and losses in lead and silver. The aim of the experiments was to supply this lack as far as laboratory work could do it.

II. Experimental Work.

The materials used in the experiments were ore, limestone and quartz. The ore was a galena concentrate from the Cœur d'Alêne district, Idaho. A screen-analysis gave the data presented in Table I., which shows that, with the exception of two grades, the 9- on 12-mesh and the through 100-mesh, the different sizes were evenly distributed. The ore was crushed to pass a 2.8-mm. screen.

TABLE I.—*Screen-Analysis of Galena from Cœur d'Alêne District, Idaho.*

Size.	Weight.	Weight.
Mesh.	Kilograms.	Per Cent.
Through 6 on 9	6	6.1
Through 9 on 12	4	17.4
Through 12 on 16	1.3	5.7
Through 16 on 20	1.55	6.7
Through 20 on 30	1.9	8.3
Through 30 on 40	1.45	6.3
Through 40 on 60	1.4	0.1
Through 60 on 100	2.0	8.7
Through 100	3.45	15.0
	23.05	100.3

The chemical analysis of an average sample gave: S, 10.58; FeO, 5.95; Al_2O_3, 4.80; SiO_2, 18.58; Zn, 2.57; Pb, 54.70; CaO, 2.20; MgO, 0.40; Ag, 0.135 (= 39.50 oz. per ton); total, 99.755 per cent. Calculation sets forth that lead and zinc are covered by sulphur, being present as galena and blende, and that, in the absence of carbon dioxide, the gangue is made up of silicate or quartz and silicate. The limestone was a pure marble, which, upon analysis, gave: SiO_2, 0.26; CaO, 55.01; MgO, 0.85; CO_2, 44 (calculated); total, 100.12 per cent. The silica added to the charges to obtain various silicates was pure quartz, assumed to contain 100 per cent. of SiO_2.

Two converters were employed for blowing the charges, one a clay crucible, the other a slag-pot. The crucible-converter, in which most of the tests were made, is represented in Fig. 1: *A* is a Morgan clay crucible No. K, with a hole 0.5 in. in diameter drilled in the bottom to admit the air-blast; *B*, an iron funnel ending in a piece of gas-pipe, connected with a T-joint, *C*, one arm of which is closed by a screw-plug, *D*. The slag-pot converter, represented in Fig. 2, is a small-size detached Devereux slag-pot. The grate, *A*, is a cast-iron plate perforated with holes 0.25 in. in diameter; the blast-inlet pipe, *B*, is screwed into the tap-hole; *C* is the hood for carrying off gases and fumes; *D*, the charging opening, closed by a hinged door. The blast for the converters was furnished by a Root blower, No. ½; the pressure was measured by a water-gauge calibrated to read in inches. The temperature measurements were made with a Le Chatelier thermo-electric pyrometer.

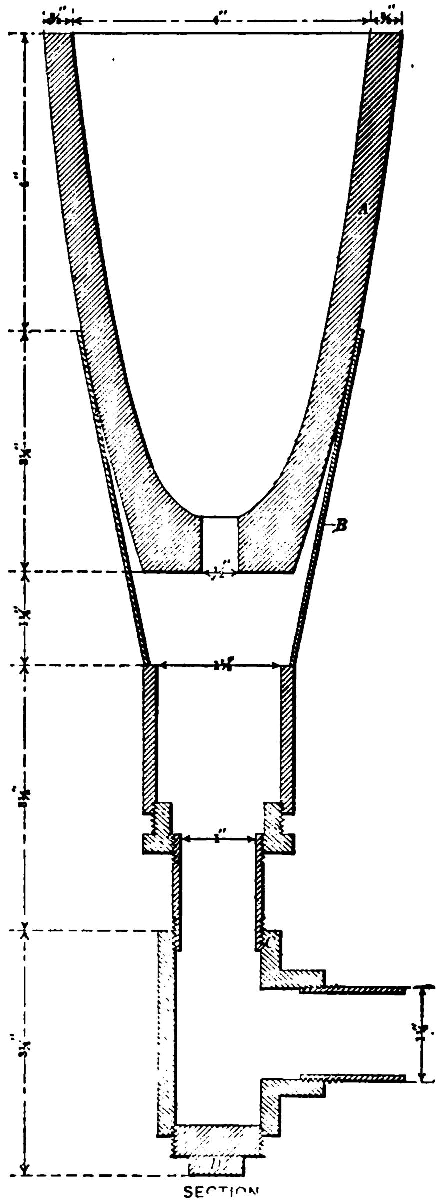
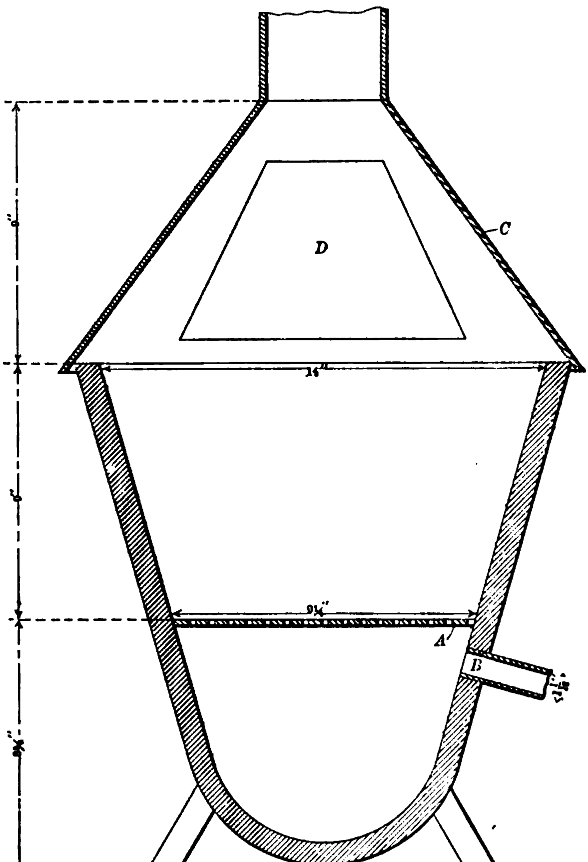


FIG. 1.—CRUCIBLE-CONVERTER.

Two series of tests were made in the crucible-converter, using 1 kg. of ore in each experiment. In the first series a singulo-silicate-slag was made the basis of calculation. Since the ore

did not contain enough silica to form a singulo-silicate after the quantity of limestone suited for lime-roasting had been added, the deficiency was made up with quartzite. In the second series, the quantities of limestone used were similar to those in the first series, but no additions of quartzite were made; the



SECTION

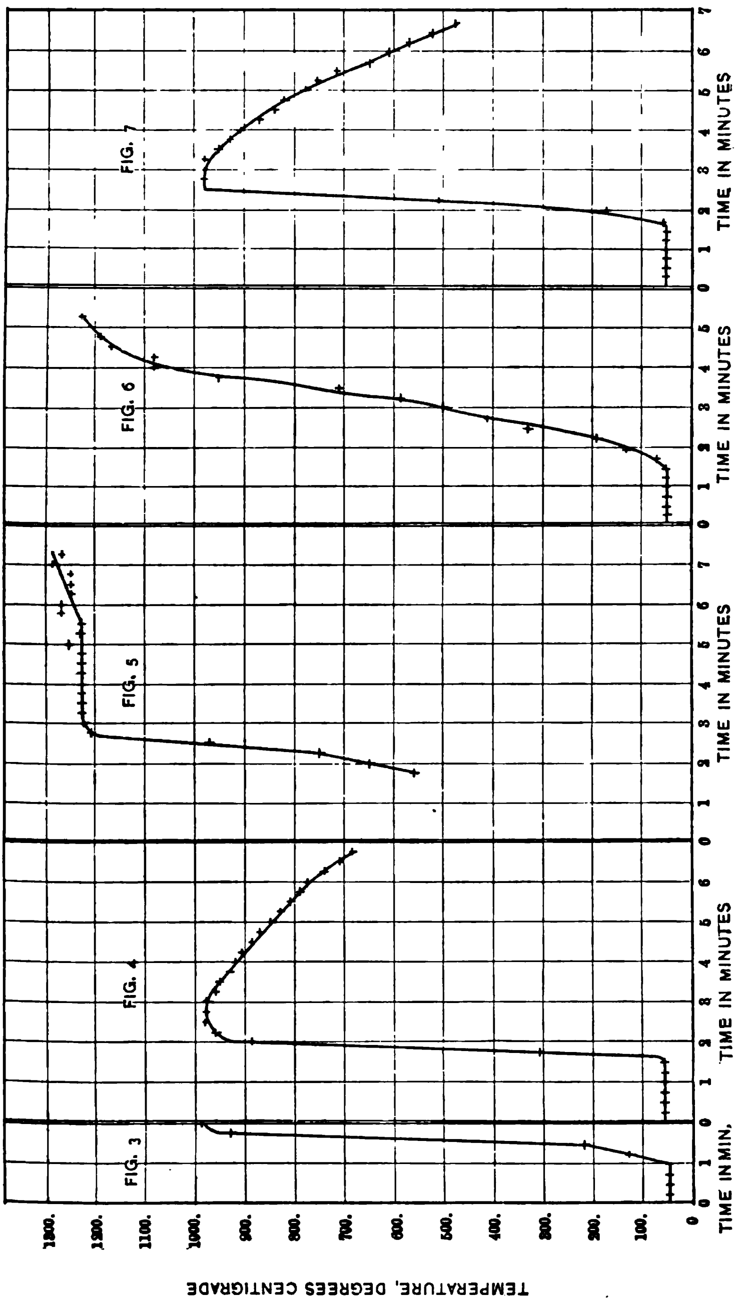
Fig. 2.—Slag-Pot Converter.

products obtained were therefore subsilicates of varying silicate degree. In conclusion, two tests were made in the slag-pot converter with 20 kg. of ore to see whether the size of charge had any effect upon the result. The charges were fluxed according to the most favorable results obtained in the experiments with 1 kg. of ore.

The modes of procedure in the small- and medium-size tests were similar. With the crucible-converter, the crucible was warmed in the ash-pit of an assay-furnace, the inside of the receiving-funnel was coated with a clay wash in order to make an air-tight joint, and the warmed crucible pressed into the funnel. A few pieces of limestone, nut-size, were placed in the bottom of the crucible to act as a grate; a thin layer of ignited charcoal was spread over the limestone, and the blast started. When the charcoal was burning freely, it was covered with a second layer of limestone of a pea-size. The charge, mixed with enough water to give it the consistency of brasque, was then fed in gradually. A thin layer was spread over the limestone, and as soon as it had become ignited and glowing spots began to appear on the surface, a second layer was added, and so on until the crucible was filled. The blast was continued until no more fumes passed off from the surface. Any blow-holes that formed, here and there, were closed by adding fresh charge or by poking down the crater-like walls of the cavities. When a charge had cooled down somewhat, it was dumped out; the coarse limestone was picked off from the bottom, the slagged and unslagged portions were separated and weighed, the slagged part was crushed, added to the pulverulent part, and the whole sampled down and assayed for sulphur, lead, and silver. A crucible could be used for several charges, as these did not attack it; it had to be replaced, however, after a few runs, as it became fissured by a longitudinal or diagonal crack, caused apparently by the unequal expansion of the clay and the iron funnel.

The slag-pot converter was warmed by burning a thin layer of charcoal on the grate with a gentle blast; otherwise, the mode of procedure was the same as just outlined.

Temperature measurements, by means of a Le Chatelier thermo-electric pyrometer, were made with five charges to see in what manner the rise in temperature took place, and to find the highest degree of heat attained in the process. Three continuous readings were taken with the crucible, and two with the slag-pot converter. The results are plotted in Figs. 3 to 7. With curves Nos. 3 and 4 the thermo-junction was fixed at about one-third the height of the crucible, with curve No. 5 at about two-thirds; with curves Nos. 6 and 7, representing the me-



Figs. 3 to 7.—Temperature Measurements in Converter.

dium-size charges, the thermo-couple was held near the center of the slag-pot. In all cases temperature-readings were begun when the ore-charge reached the junction, and then continued at intervals of 15 seconds. In curve No. 3 the two thermo-wires parted at 990° C., in curve No. 6 the galvanometer ceased to act at 1,220° C. for some unexplained reason, and in curve No. 5 there was a halt at the same temperature, followed by a rise after a few minutes' interval. These imperfect records are given, as they show, as far as they go, features similar to those of the complete records. The five curves all show a sudden quick rise of temperature to a maximum of 980° C. with the small charges, and to an apparent maximum of 1,225° C. with the medium-size charges. The subsequent gradual fall of temperature is seen only in curves 4 and 7.

III. Record of Results.

The results obtained from the seventeen tests made are recorded in Tables II., III., and IV., and the data of the 15 small-size charges relating to the elimination of sulphur and the loss in lead and silver are represented graphically in Figs. 8 to 19.

Table II. and Figs. 8 to 11 represent the singulo-silicate series of tests. The weight of a charge had to be adapted to the size of the crucible; with small quantities of flux 1,000 g. was taken; with increasing quantities, the weight had to be reduced. The percentage of limestone of the charge ranged from 4.7 to 30, and the necessary silica varied accordingly. The mixtures were moistened in each case with 5 per cent. of water. The time it took to fill a crucible varied from 4 to 9 min., the blast being kept constant at 2 in. pressure. In two cases this pressure was maintained throughout, in four it was raised to 6 in., and in four to 10 in.

The runs lasted from 14 to 18 min. The blown product weighed less than the original charge, as was to be expected. The data giving the percentages of slagged and pulverulent parts of the blown charges show that limestone could form as much as 24 per cent. of the weight of the charge, and this when blown still furnish more than 95 per cent. of slagged material. When, however, this quantity of limestone was exceeded, and the lead in the charge reduced to less than 33.72 per cent., and the sulphur to less than 6.36 per cent., the heat generated was

TABLE II.—*Singulo-Silicate Series.*

	Number of charge	1	2	3	4	4a	4b	5	6	6a	7
Charge.	Ore, grams	1,000	1,000	1,000	1,000	1,000	1,000	813	800	800	667
	Limestone, grams	50	120	150	200	200	200	217	276	276	325
	Silica, grams	...	17.8	33.3	52	52	52	55.4	72	72	88
	Water, per cent	5	5	5	5	5	5	5	5	5	5
	Limestone, per cent. of charge	4.7	10.6	12.7	16	16	16	20	24	24	30
	Time taken feeding, min	4	5.5	5	8	6	5.5	7	9	8	9
	Duration of run, min	8	16	14	17	15	12	16	18	17	12
Blast.	Pressure while charging, in. water	2	2.5	2.25	2	2	2	2	2	2	2
	Pressure, maximum, in. water	2	10	10	10	2	10	6	6.5	6	6.5
Product.	Weight, grams	930	1,015	1,055	1,105	1,117	1,115	970	1,035	1,038	945
	Slagged part, per cent	100	96.35	98.56	100	96.3	97.8	97.5	95.2	96.9	00
	Pulverulent part, per cent	00	3.65	1.44	00	3.7	2.2	2.5	4.8	3.1	100
Sulphur.	Sulphur in ore-charge, grams	104	104	104	104	104	104	84.5	83.2	83.2	69.4
	Sulphur in ore-charge, per cent	9.91	9.14	8.77	8.31	8.31	8.31	7.72	7.26	7.67	6.36
	Sulphur in product, per cent	6.73	5.22	4.3	3.75	3.77	3.81	3.56	3.61	3.46	3.58
	Sulphur in product, grams	62.6	52.98	45.36	41.5	42.1	42.4	34.5	37.5	35.9	33.8
	Sulphur eliminated, per cent	39.8	49.0	56.5	60.1	59.5	61.4	59.4	54.9	59.2	51.2
Lead.	Lead in ore-charge, grams	547	547	547	547	547	547	444	437	437	364
	Lead in ore-charge, per cent	52.1	48.1	46.24	43.83	43.83	43.83	40.9	38.18	40.3	33.72
	Lead in product, per cent	57.31	52.60	50.60	47.23	48.65	50.4	45.77	40.65	44.5	38.83
	Lead in product, grams	533	533.8	534	521.9	544	562	444	422	462	364
	Lead lost, per cent	2.55	2.39	2.37	4.6	0.55	2.6	0.0	3.56	0.0	0.0
Silver.	Silver in ore-charge, grams	1.363	1.363	1.363	1.363	1.363	1.363	1.089	1.070	1.070	0.892
	Silver in product, grams	1.320	1.329	1.305	1.264	1.272	1.273	1.024	1.023	1.007	0.862
	Silver lost, per cent	1.33	2.49	4.24	7.26	4.98	4.86	5.97	4.39	5.88	3.36

insufficient to fuse the charge; this remained pulverulent, with here and there an agglomerated particle distributed through it. Slagged ore had the general characteristics of ore that has been agglomerated on the hearth of a hand-reverberatory roasting-furnace; the color, however, was more greenish-brown than black; it was tough, and the hardness increased as the additions of limestone decreased; wherever the elimination of sulphur was imperfect, streaks or bunches of undecomposed galena could be easily traced.

Curves Nos. 8 and 9, representing the percentage of sulphur remaining in the blown charge and the percentage of sulphur eliminated, show that in a charge the percentage of sulphur decreases as that of limestone increases until the latter reaches 26.7 per cent., and that from this point on the residual sulphur remains constant at 3.5 per cent. On the basis of percentage of sulphur eliminated, the maximum of 60 per cent. is reached with a charge containing between 20 and 26.7 per cent. of limestone, and then begins to decrease. In curve No. 10 the loss of lead remains constant at 2.5 per cent. with increasing limestone until from 15 to 20 per cent. has been reached; it then drops quickly to zero with 26.7 per cent. and

SINGULO-SILICATE SERIES.

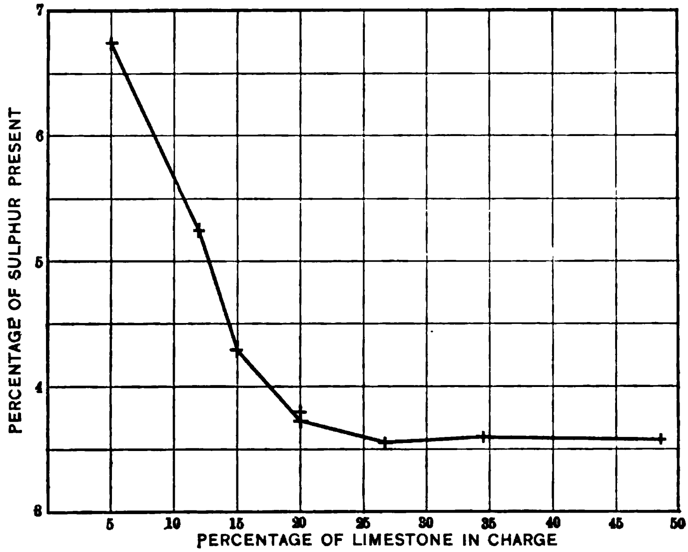


FIG. 8.—Residual Sulphur.

SINGULO-SILICATE SERIES.

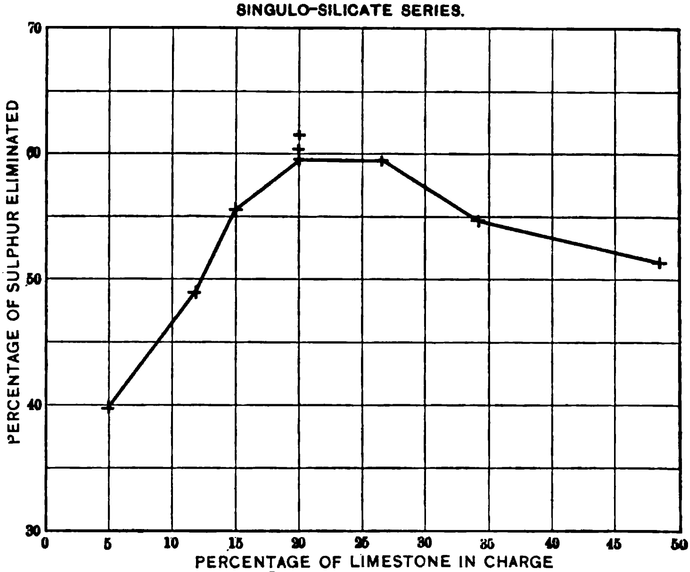


FIG. 9.—Eliminated Sulphur.

FIGS. 8 and 9.—RESIDUAL AND ELIMINATED SULPHUR.

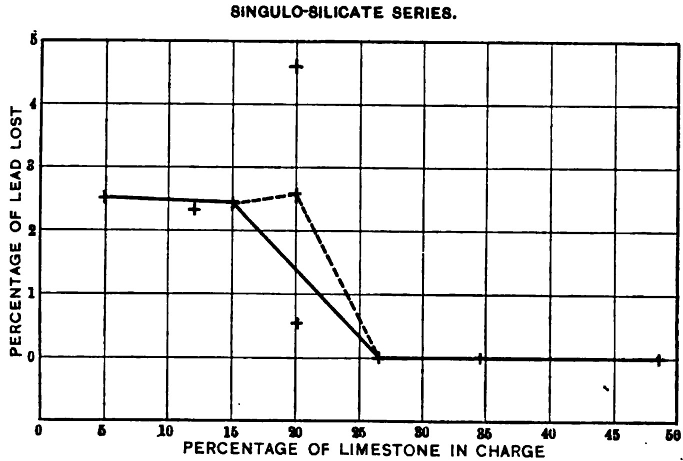


Fig. 10.—Loss of Lead.

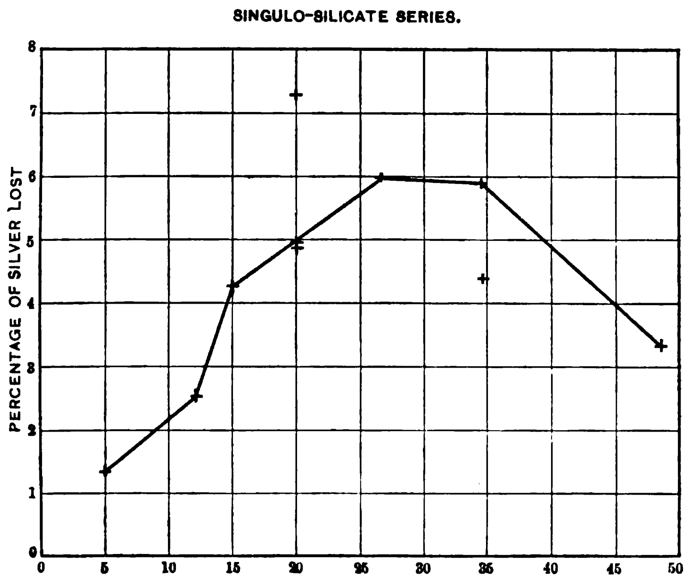


Fig. 11.—Loss of Silver.

Figs. 10 and 11.—Loss of Lead and Silver.

SUBSILICATE SERIES.

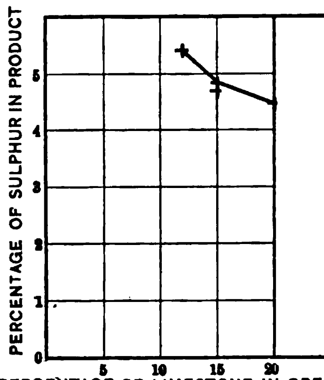


FIG. 12.—High-Pressure Blast.

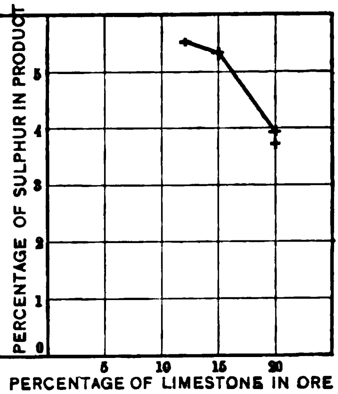


FIG. 14.—Low-Pressure Blast.

SUBSILICATE SERIES.

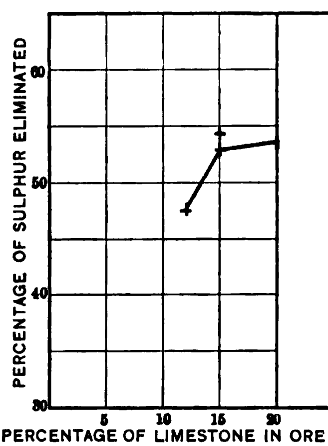


FIG. 13.—High-Pressure Blast.

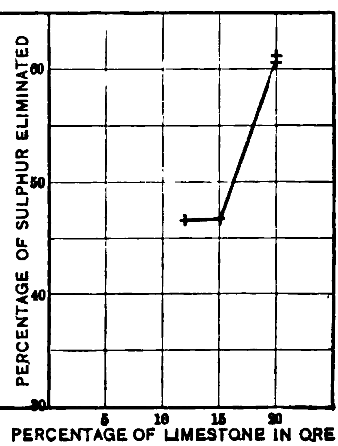


FIG. 15.—Low-Pressure Blast.

FIGS. 12 to 15.—RESIDUAL AND ELIMINATED SULPHUR.

remains unchanged. The loss in silver, represented by curve No. 11, does not follow that of the lead; on the contrary, it increases with additions of limestone to 6 per cent. and then falls, at first gradually, and later more quickly. As limestone forming 26.7 per cent. of the weight of the charge is the permissible limit, if, when blown, it is to be satisfactorily slagged, it may be inferred that, for practical purposes, the loss in silver increases with the additions of limestone. If curve No. 11 is compared with curve No. 9, a similarity between the two will

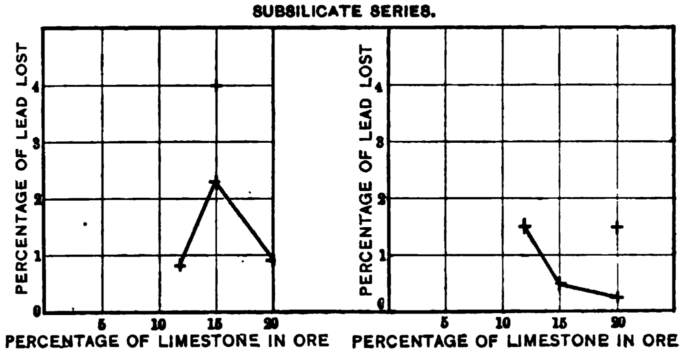


FIG. 16.—High-Pressure Blast. FIG. 17.—Low-Pressure Blast.

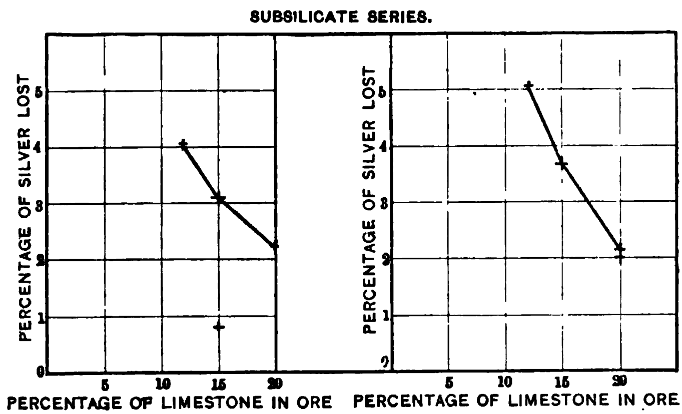


FIG. 18.—High-Pressure Blast. FIG. 19.—Low-Pressure Blast.

FIGS. 16 to 19.—LOSS OF LEAD AND SILVER.

be seen, indicating that the loss in silver increases with the elimination of sulphur.

Table III., giving the data of the subsilicate series, is arranged in the same manner as Table II. There is an additional heading, giving the silicate-degree of the charge; furthermore, charges Nos. 8, 9, 9*a* and 10 have been run with a high-pressure blast, and in charges Nos. 11, 12, 13 and 13*a*, of similar composition, the initial blast-pressure of 2 in. has been kept constant.

Curves Nos. 12 to 19 represent graphically the data relating to the elimination of sulphur and the loss of lead and of silver. The proportions of slagged and pulverulent parts of a charge remained satisfactory as long as the addition of limestone did not exceed 20 per cent. of the weight of the ore, and with it

TABLE III.—*Subsilicate Series.*

	Number of charge	8	9	9a	10	11	12	13	13a
Charge.	Ore, grams	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
	Limestone, grams	120	150	150	200	120	150	200	200
	Silica, grams	....	....	....	...	....	....	....	....
	Water, per cent	5	5	5	5	5	5	5	5
	Limestone, per cent. of charge	10.7	13	13	16.6	10.7	13	16.6	16.6
	Silicate degree, O base: O acid	1.03:1	1.06:1	1.06:1	1.12:1	1.03:1	1.06:1	1.12:1	1.12:1
	Time taken feeding, min	5.5	5.5	7.5	8	5	4.75	6	9.5
	Duration of run, min	18	14	14	17	16	17	17	18
Blast.	Pressure while charging, in. water	2.25	2.5	2	2.5	2	2	2	2
	Pressure, maximum, in. water	8.25	10	6	10	2	2	2	2
Product.	Weight, grams	1,012	1,014	1,035	1,087	1,020	1,035	1,080	1,107
	Slagged part, per cent	98	96.35	98.1	86.9	98.1	98.1	98.8	95.6
	Pulverulent part, per cent	2	3.65	1.9	13.1	1.9	1.9	1.2	4.4
Sulphur.	Sulphur in ore-charge, grams	104	104	104	104	104	104	104	104
	Sulphur in ore-charge, per cent	9.3	9.0	9.0	8.7	9.3	9.0	8.7	8.7
	Sulphur in product, per cent	5.4	4.7	4.85	4.45	5.47	5.35	3.76	3.91
	Sulphur in product, grams	54.6	48.9	50.2	48.4	55.7	55.4	40.6	43.2
	Sulphur eliminated, per cent	47.6	53	54.4	53.4	46.4	46.7	61.0	60.8
Lead.	Lead in ore-charge, grams	547	547	547	547	547	547	547	547
	Lead in ore-charge, per cent	48.8	47.6	47.6	45.6	48.8	47.6	45.6	45.6
	Lead in product, per cent	53.6	50.45	54.5	49.85	52.8	52.5	50.44	52.25
	Lead in product, grams	543	525	564	542	539	544	545	568
	Lead lost, per cent	0.7	3.8	2.25	0.9	1.46	0.55	0.36	1.56
Silver.	Silver in ore-charge, grams	1.363	1.363	1.363	1.363	1.363	1.363	1.363	1.363
	Silver in product, grams	1.308	1.352	1.297	1.334	1.270	1.288	1.311	1.310
	Silver lost, per cent	4.04	0.8	3.07	2.13	5.08	3.74	2.02	2.09

the percentage of sulphur was not reduced below 8.7 per cent. and that of lead below 45.6 per cent.; beyond these limits the blown charge was not sufficiently coherent to be suited for a blast-furnace charge. Curves Nos. 12 to 15 show that the residual sulphur (3.76 to 5.47 per cent.) and the sulphur eliminated (46.4 to 60.8 per cent.) decrease with the addition of limestone until this forms 20 per cent. of the ore. A comparison of curve No. 12 with No. 14, and of curve No. 13 with No. 15, shows that, with a high pressure, the oxidation of sulphur proceeds more quickly than with a low pressure, but that it is not so effective; the percentages of residual sulphur are greater and the percentages of elimination smaller. Comparing curves Nos. 14 and 15 of the low-blast subsilicate series with the corresponding curves Nos. 8 and 9 of the singulo-silicate series, there is found little difference between the residual sulphur, 4.00 *vs.* 3.75 per cent., and the eliminated sulphur, 60.5 *vs.* 59.5 per cent. The loss in lead, curves Nos. 16 and 17, is greater with high- than with low-pressure blast. This is due, no doubt, to the greater prevalence of blow-holes with the former. It is greater in the subsilicate than in the singulo-silicate series. The

probable explanation is to be found in the presence of a smaller amount of slag-forming material for a given quantity of lead. The loss in silver with the subsilicate series is shown in curves Nos. 18 and 19. The general trend of the curves is the same for high- and low-pressure blast, but it is directly opposed to that of curve No. 11 of the singulo-silicate series, in which the

TABLE IV.—*Medium-Size Singulo-Silicate Charges.*

	Number of charge	16	17
Charge.	Ore, kg	20	20
	Limestone, kg	4	5.4
	Silica, kg	1.04	1.35
	Water, kg	0.75	1.33
	Limestone, per cent. of charge	16	20
	Time taken feeding, min	15	15
	Duration of run, min	45	45
Blast.	Pressure while charging, in. water	5	7
	Pressure, maximum, in. water	12	14½
Product.	Weight of product, kg	23.2	23.6
Sulphur.	Sulphur in ore-charge, grams	2,100	2,100
	Sulphur in ore-charge, per cent	8.42	7.85
	Sulphur in product, per cent	3.85	3.55
	Sulphur in product, grams	893	838
	Sulphur eliminated, grams	1,206	1,262
	Sulphur eliminated, per cent	57.4	60.2
Lead.	Lead in ore-charge, grams	11,300	11,300
	Lead in ore-charge, per cent	45.3	42.2
	Lead in product, per cent	48.6	47.15
	Lead in product, grams	11,190	11,130
	Lead lost, grams	10	170
	Lead lost, per cent	0.08	1.50
Silver.	Silver in ore-charge, grams	26.760	27.760
	Silver in product, grams	26.580	26.550
	Silver lost, grams	0.180	0.210
	Silver lost, per cent	0.67	0.78

loss in silver was shown to increase with the percentage of limestone. This would seem to point to a possible effect of the presence of a larger or smaller amount of silica, but the relation, if there is any, is not sufficiently clear at present to draw any inferences.

Table IV. gives the data of the two tests made with singulo-silicate charges using 20 kg. of ore. In order to compare the effect of the size of charge, the leading data are brought together in Table V.

TABLE V.—*Comparison of Large and Small Singulo-Silicate Charges.*

Size of Charge.	Large.		Small.	
Limestone added, per cent	20	26.7	20	26.7
Sulphur in product, per cent	3.85	3.55	3.75	3.55
Sulphur eliminated, per cent	57.4	60.2	60.0	59.4
Lead lost, per cent	0.08	1.50	1.50	0.00
Silver lost, per cent	0.67	0.78	4.90	5.90

Table V. shows only one decided difference—viz., that the loss in silver is very much greater with a small than with a large charge. There is no reason apparent why this should be the case. Without a larger number of tests to substantiate the greater loss, this, for the present, must be considered as accidental.

IV. CONCLUSION.

The above experiments were carried on with a single ore, and the results find direct application only to this ore or to one very similar to it. Nevertheless, they have a more general application; they point to the conclusions:

1. That in lime-roasting a siliceous galena concentrate low in blende, charges containing a wide range of lime and silica, and little iron, can be successfully blown.

2. That a singulo-silicate charge, with limestone equal to from 20 to 26 per cent. of the weight of the ore, gives most satisfactory results as regards the physical condition of the product, the elimination of sulphur, and the loss of lead and silver.

3. That the same is true with a subsilicate charge with limestone equal to 20 per cent. of the weight of the ore.

4. That a low-pressure blast is a better desulphurizer and causes less loss than a high-pressure blast.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Roasting of the Argentiferous Cobalt-Nickel Arsenides of Temiskaming, Ontario, Canada.

BY HENRY M. HOWE, LL.D., WILLIAM CAMPBELL, PH.D., AND CYRIL W. KNIGHT, B.SC.*

(New York Meeting, April, 1907.)

THIS paper gives the results of an investigation of the behavior of the argentiferous cobalt-nickel arsenides of Temiskaming, Ontario, in roasting, made in the metallurgical laboratories of the School of Mines of Columbia University in the City of New York. The ore was kindly given by the owners of the La Rose and Trethewey properties at Cobalt, Ontario, and Mr. E. J. Hall, Tutor in Assaying in Columbia University, has helped us much.

I. OBJECT OF THE INVESTIGATION.

The object of the investigation was to learn:—

1. The temperature at which the arsenic is most rapidly expelled;
2. The thoroughness with which it is expelled by prolonged roasting at this temperature;
3. The effect of adding charcoal (a) near the end of the roast and (b) at the beginning of the roast.

II. NATURE OF THE ORE.

The important ores mined in the Temiskaming deposits are: native silver—with small amounts of dyscrasite (Ag_6 Sb), argentite (Ag_2S), pyrargyrite (Ag_3SbS_3)—smaltite ($CoAs_2$), chloanthite ($NiAs_2$) and niccolite (NiAs). Mispickel (FeAsS) and cobaltite (CoAsS) also occur in smaller quantities. The average composition of the ore shipped from this district for the first six months of 1905 was: silver, from 4.1 to 4.8 per cent.; cobalt, from 6.9 to 8.2 per cent.; nickel, from 3 to 4.7 per cent.; and arsenic, from 30.9 to 34.6 per cent. The ore which we treated consists chiefly of smaltite. In our laboratory-work

* Respectively Professor, Instructor and Student of Metallurgy in the School of Mines of Columbia University in the City of New York.

the temperature was kept below the melting-point of silver (960° C.) in order to prevent loss of that metal, though our preliminary experiments showed that these ores do not frit or clog at this or even at a somewhat higher temperature.

The Temiskaming ores contain little gold, only $0.40 per ton in case of the ores which we treated.

III. Sampling and Assaying.

About 43 lb. of the ore, in lumps about 3-in. cubes, were crushed so as to pass through a sieve of 20 meshes to the linear inch. In this crushing we caught and separated particles of metallic silver which represented about 75 oz. of silver to the ton of ore, or about 11 per cent. of its total value. Some of these particles were about 0.25 in. in diameter.

For assaying, a lot of 37 assay-tons was next separated from this crushed product by means of a "split" sampler, and then ground so as to pass a sieve of 100 meshes to the linear inch. In doing this a second lot of metallic silver particles, representing 117 oz. per ton of ore, was separated.

The results of 12 crucible-assays and 9 scorification assays were:—

Metallic silver by the crucible process,	477 oz. per ton of ore.
Metallic silver by the scorification process,	497 oz. per ton of ore.
Add metallic silver separated in crushing,	75 oz. per ton of ore.
Add metallic silver separated in grinding,	117 oz. per ton of ore.
Total silver-content,	689 oz. per ton of ore.

The ore contains 56 per cent. of arsenic.

For the silver-assay the following quantities were used: For scorification, 0.2 A. T. of ore was roughly divided into halves, each of which was scorified with 60 g. of lead and 1 g. of borax-glass. The resulting two beads were weighed together. For the crucible process, 0.5 A. T. of ore, 2.5 A. T. of lead oxide, $\frac{2}{3}$ A. T. of soda, $\frac{1}{3}$ A. T. of borax-glass, and 4.5 g. of argol were used.

IV. The Roasting.

The roasting was done in an American Gas Furnace Company's oven No. 2 (Fig. 1), 27 in. long and 20 in. wide inside.

The ore was held in shallow iron pans resting on the hearth of this furnace, and lined with 0.5 in. of fire-brick.

The temperature was measured by means of a Le Chatelier pyrometer. The thermo-couple, C, was protected from arsenic and other fumes by a porcelain tube, D, and was placed immediately above the ore, A. It entered through a circular hole, E, in the back of the furnace, and was connected with a Keiser and Schmidt galvanometer, standardized by means of the melting-points of zinc, aluminum and copper. The temperature was recorded and the ore rabbled every 10 min. In none of the roasts was any fritting or clogging of the ore noticed.

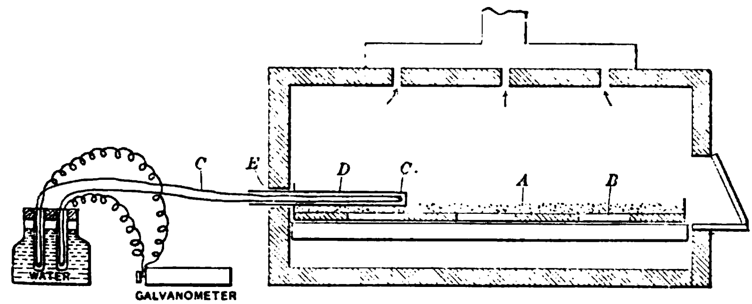


FIG. 1.—SECTION OF THE OPEN GAS FURNACE IN WHICH THE ORE WAS ROASTED, SHOWING THE ARRANGEMENT OF THERMO-COUPLE FOR INDICATING THE TEMPERATURE.

V. AT WHAT TEMPERATURE IS THE ARSENIC EXPELLED MOST RAPIDLY?

Roast No. 1.—In this test, 3.5 lb. of the ore, crushed to pass a 20-mesh sieve, were placed in the furnace, the temperature of which had previously been raised to 490° C. The temperature was then gradually raised at the rate of about 120° C. per hour, until it finally reached its highest point, 870° C. Samples were taken with the usual precautions, and their arsenic was determined by fusion with sodium peroxide, neutralizing with acetic acid and sodium hydroxide (using phenolphthalin as an indicator), precipitation as silver arsenate with silver nitrate, and titrating with ammonium thiocyanate.[1]

The results of the roast are given in Table I., and graphically in Fig. 2.

Though the arsenic escaped pretty rapidly at first, yet towards the end of the second hour its escape was almost com-

[1] Miller's *Quantitative Analysis for Mining Engineers*, p. 114.

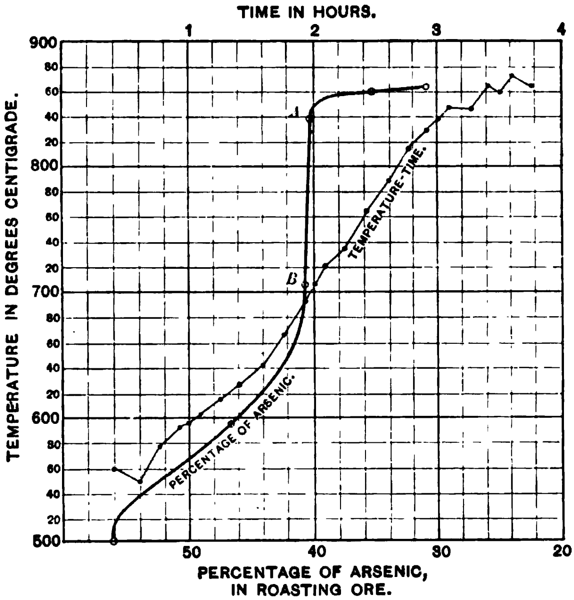


FIG. 2.—DIAGRAMMATIC RECORD OF ROAST No. 1. (See Table I.)

TABLE I.—*Record of Roast No. 1. Gradually Rising Temperature.*

Temperature of Roast.	Time from the Beginning.	Quantity of Arsenic in Ore at Different Stages of the Roast.
Degrees Centigrade.	Hr. Min.	Per Cent.
490	0 : 0.0	55.9
559	0 : 25	
547	0 : 35	
577	0 : 45	
591	0 : 55	
596	1 : 00	46.6
601	1 : 05	
611	1 : 15	
624	1 : 25	
641	1 : 35	
666	1 : 45	
691	1 : 55	
706	2 : 00	40.7
721	2 : 05	
735	2 : 15	
763	2 : 25	
788	2 : 35	
814	2 : 45	
828	2 : 55	
838	3 : 00	40.3
848	3 : 05	
844	3 : 15	
864	3 : 25	
858	3 : 30	35.4
872	3 : 35	
863	3 : 45	31.0

pletely arrested, in spite of the continued regular rise in temperature, as shown by the nearly vertical part *A B* of the arsenic-line in the figure. But when the temperature reached 840°, the expulsion of arsenic again became rapid, as is shown by the sharp bend of the arsenic-curve to the right at the point *A*. These results tend to prove that the behavior of smaltite resembles that of pyrite, of which the first atom of sulphur is removed at a much lower temperature than the second.

Conclusions.—1. That 15 per cent. of arsenic (per 100 of

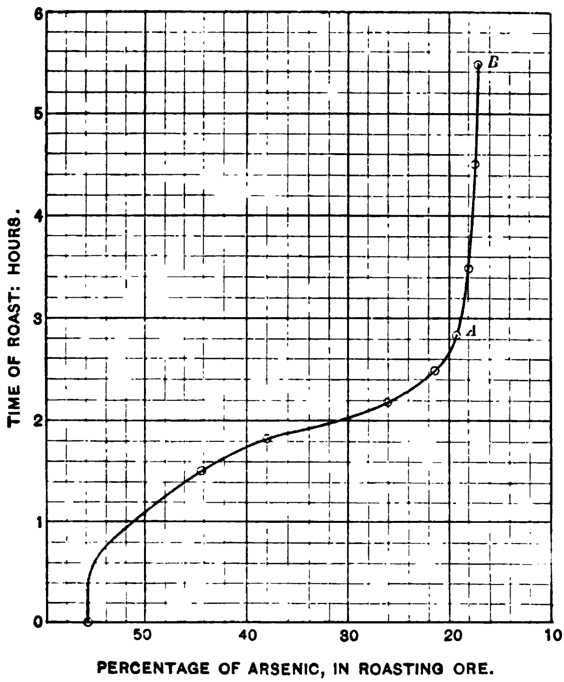


FIG. 3.—DIAGRAMMATIC RECORD OF ROAST NO. 2. (See Table II.)

ore), i.e. 27 per cent. of the total arsenic, is expelled below 700° C.

2. That the rest of the arsenic is not expelled until the temperature reaches about 840°, when rapid expulsion again sets in.

VI. HOW THOROUGHLY CAN ARSENIC BE EXPELLED AT 890° C.?

Roast No. 2.—In this roast about 3 lb. of ore, ground to pass a sieve of 20 meshes to the linear inch, were raised quickly to

about 890° C. (a temperature a little above that which Roast No. 1 had shown that arsenic is rapidly expelled), and held near that temperature for about four hours, with frequent rabbling.

As shown in Table II. and Fig. 3, the arsenic was expelled fairly rapidly until it had fallen to about 20 per cent., but thereafter very slowly.

TABLE II.—*Record of Roast No.* 2. *Temperature Held Near* 890° *C.*

Temperature of Roast. Room Temperature.	Time.	Quantity of Arsenic in Ore at Different Stages of the Roast.
Degrees Centigrade.	Hr. Min.	Per Cent.
463	0 : 35	55.9
533	0 : 45	
622	0 : 55	
693	1 : 05	
738	1 : 15	
795	1 : 25	
846	1 : 35	44.6
895	1 : 45	
895	1 : 55	38.0
909	2 : 05	
897	2 : 15	26.3
901	2 : 25	
886	2 : 35	21.7
883	2 : 45	
883	2 : 55	19.3
883	3 : 05	
885	3 : 15	
889	3 : 25	
883	3 : 35	18.3
891	3 : 45	
894	3 : 55	
899	4 : 05	
897	4 : 15	
902	4 : 25	
900	4 : 35	17.5
900	4 : 45	
898	4 : 55	
887	5 : 05	
883	5 : 15	
878	5 : 35	17.3

VII. Does Charcoal Added after Roasting at 890° Cause Further Expulsion of Arsenic?

Table III.—*Record of Roast No. 3. Charcoal Added After Roasting Near 890° C.*

Temperature of Roast. Room Temperature.	Time from the Beginning.	Quantity of Arsenic in Ore at Different Stages of the Roast.
Degrees Centigrade.	Hr. Min.	Per Cent.
470	0 : 35	55.9
606	0 : 45	
660	0 : 55	
723	1 : 05	
815	1 : 15	
856	1 : 25	
873	1 : 35	
886	1 : 45	
872	1 : 55	
864	2 : 05	
870	2 : 15	
874	2 : 25	
888	2 : 35	
875	2 : 45	
897	2 : 55	
890	3 : 05	15.8
	Charcoal added here.	
882	3 : 20	
882	3 : 35	
894	3 : 50	
884	4 : 05	15.0

Roast No. 3.—In order to learn whether an addition of charcoal after long roasting between 840° and 890° C. (temperatures between which we had found that arsenic is expelled rapidly) causes further expulsion of arsenic by reducing the fixed arsenates to the volatile forms of arsenious acid and metallic arsenic, one of us roasted a third lot of ore at temperatures between 870° and 890° for 1.5 hr., and, without removing it from the furnace, he then stirred in 10 per cent. by weight of charcoal, ground so as to pass a sieve of 10 meshes to the linear inch, but not one of 20 meshes. The results are shown in Table III. If too coarse, charcoal disintegrates and scatters the ore, and if too fine it burns away too fast.

At the time of adding the charcoal, fumes of arsenic had ceased to be visible, but this addition caused a sudden evolution of dense fumes, which lasted for only a few minutes.

The charcoal had little effect on the arsenic. Before its addition the ore contained 15.8 per cent. of arsenic, and 1 hr. later this had fallen only to 15 per cent.

In this roast, after the ore had been exposed to a temperature above 856° for 1 hr. 40 min., its arsenic-content had fallen to 15.8 per cent., whereas in Roast No. 2, after it had been exposed 2 hr. to temperatures above 846°, it still contained 18.3 per cent. of arsenic. This difference tends to show that unnoticed variations in conditions may materially influence the rate of expulsion, as is the case in many roasting-operations.

The fact that the arsenic was expelled in this roast, before the addition of the charcoal, more thoroughly than in any of the others, in spite of the very rapid raising of the temperature at the beginning, goes to show that the behavior of smaltite differs in an important way from that of pyrite, the temperature of which must be raised very carefully and slowly, lest the fritting or enamelling of the outer surface of the individual particles prevent the free access of the air to their interior, and thus arrest the roast.

VIII. Does Charcoal Added at the Beginning of the Roast Increase the Expulsion of Arsenic?

Roast No. 4.—About 2 lb. of ore were mixed with 10 per cent. by weight of charcoal, raised to 880° in 2 hr., and held near that temperature for 1.75 hr. more, or a total of 3. hr. 45 min. The charcoal seems to have had little effect, because at the end of this time the ore still contained 17.5 per cent. of arsenic, or more than in Roast No. 3 after it had been above 856° for 1 hr. 40 min., and but little less than in Roast No. 2 after it had been above 795° for 2 hr. 10 min.; and in each of these latter cases the expulsion of arsenic was brought about without the use of charcoal.

These cases are here recapitulated:—

Roast.	After Remaining Above	For	The Ore Still Contained
No. 2.	846° without charcoal.	2 hr.	18.3 per cent. of arsenic.
No. 3.	856° without charcoal.	1 hr. 40 min.	15.8 per cent. of arsenic.
No. 4.	880° with charcoal.	1 hr. 45 min.	17.5 per cent. of arsenic.

IX. Does Finer Grinding Increase the Expulsion of Arsenic?

Roast No. 5.—In order to learn whether finer grinding would lead to further expulsion of arsenic by exposing the ore more fully to the air, the ore which had already undergone Roast No. 3 was re-ground so as to pass a sieve of 100 meshes to the linear inch, and re-roasted for 2 hr. 30 min. at about 880° C.; but this re-roasting caused no farther expulsion of arsenic.

X. Summary of Results.

The following conclusions apply only to the particular ore here treated:—

1. The percentage of silver as determined by the scorification-method is about 4 per cent. higher than as determined by the crucible-method.

2. The ore neither clogs nor frits at or even somewhat above 960°, the melting-point of silver.

3. The arsenic can be reduced from about 56 to 41 per cent., or by 15 per cent., by roasting below 700° C. (Roast No. 1, Table I., Fig. 2.)

4. It can be further reduced by about 24 per cent., viz.:—to 17 per cent., by roasting at temperatures above 840°, and in this higher range the arsenic is removed much faster than at lower temperatures. (Roast No. 2, Table II., and Fig. 3.)

5. Hence our inference that the behavior of smaltite in roasting is probably analogous to that of pyrite, which loses its first atom of sulphur much more readily than its second; yet, unlike pyrite, this ore may be raised suddenly to 800° without harm, because, unlike pyrite, it does not frit or enamel when thus suddenly heated, but remains open and porous, so that the air may penetrate it. (Roast No. 3.)

6. Charcoal, whether added at the beginning or towards the end of the roast, fails to increase the expulsion of arsenic. (Roasts Nos. 3 and 4.)

7. We doubt whether it will pay to reduce the arsenic-content below 20 per cent., even by roasting at temperatures above 890° C., because its further reduction is very slow.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Grinding in Tube-Mills at the Waihi Gold-Mine, Waihi, New Zealand.

BY E. G. BANKS, WAIHI, AUCKLAND, NEW ZEALAND.

(New York Meeting, April, 1907.)

THIS paper is presented in the belief that metallurgists and chemists will be interested in the practice of grinding in tube-mills in connection with stamps, especially since the records of working here given extend over a lengthy period of time (since May, 1905).

The ore from the Waihi mine—more especially that produced in the upper levels—contains a large proportion of hard, chalcedonic quartz, and the gold exists in an exceedingly fine state, conditions which necessitate very fine crushing in order to obtain a high extraction of the precious metal.

Before the introduction of tube-mills at the 90-stamp Waihi mill, it was found necessary to stamp through 40-mesh (1,600 holes per sq. in.) woven wire-screens, having a fairly high discharge. The pulp then graded:

	Per Cent.		Per Cent.
On 50-mesh,	0.1	On 120-mesh,	8.77
On 60-mesh,	8.74	On 150-mesh,	7.48
On 80-mesh,	16.06	Passed 150-mesh,	55.19
On 100-mesh,	3.66		

The stamp-duty was 2.89 short tons per stamp per day, or a total of 260 tons daily.

Although the extraction on this pulp was: gold, from 88 to 90 per cent., and silver, from 74 to 78 per cent., it was recognized that finer grinding of the sands would prove beneficial, provided a machine could be found to do this work economically. Various grinding-mills and pans were tried, but without satisfactory results, the particles of sand being so hard that the capacity of any of the machines was too small to be economical.

The results of grinding in tube-mills in other countries were so satisfactory that three tube-mills were erected at the Waihi

mill, the installation being completed in May, 1905, since which time an average duty of about 2.7 mills has been maintained. The mills are of the Davidsen, 22-ft. type, and are run at a speed of 27.5 rev. per min. Each mill is loaded with 5.5 tons of flints, and requires 50 h.p. to operate it. The mills are stopped for inspection and addition of flints once a week. The quantity of flints consumed is 18 cwt. per mill per week. In order to reduce the time required to charge the flints into the tube-mill, a new door is being fitted which will admit of two or three charges a week instead of only one, as formerly. In this way the weight of the flints in the mill can be kept at all times much nearer the weight of the original charge, 5.5 tons.

Various liners have been used, including "Silex" and "Delarue" quartzite blocks, and also cast-iron liners, 1.25 in. thick. The iron liners last about as long as the quartzite blocks—viz., 2.5 months—but the grinding-result is not so good. A new lining, invented and patented by Mr. H. P. Barry, called the "Honeycomb lining," is now being tried with very promising results. This liner consists of a light cast-iron frame, 22 by 14 by 3 in. deep, shaped to the curve of the mill. Thin walls divide this lining into 4 or 6 compartments. A temporary sheet-iron back is fastened to the frame, and each compartment is then firmly packed with rough lumps of hard quartz or quartzite, varying in size up to 4 in. square, bedded-in with a mixture of Portland cement, coarse sand and fine sand. The liners so formed are allowed to set, preferably under exhaust steam, for several weeks—the longer the better—before being placed in the mill. This method of lining calls for a much shorter stoppage than with the quartzite blocks. The frames fit neatly with each other and with the shell of the mill, and only a small quantity of cementing material is required.

If made with hard material these liners stand very well, and cost, including labor, about $175, as compared with $400 for lining with quartzite blocks. The grinding-efficiency of a mill with this new liner appears to be quite equal to that of the quartzite blocks.

The stamps weigh 1,000 lb., and crush through 20-mesh screens. The proportion of water to ore is 10 to 1, and the output is 354 tons per day, which is equivalent to about 4 short tons per stamp.

The pulp is lifted by wheel-elevators to 4 sizing-boxes, each 4 ft. square and 4 ft. deep; no upward flow is used. The slime and fine sand overflow and pass to the treatment-plant. The coarse sand, having 2 parts of water to 1 of sand, is divided into three portions and flows directly to the mills. It is intended to put in a de-watering-box at the head of each mill, with a view to improve the grinding.

The grade of the pulp, before and after the mill-treatment, is:

Size.	Before Grinding (90 Stamps, on 20-Mesh).		After Grinding in Three Tube-Mills.	
	Per Cent.	Tons.	Per Cent.	Tons.
On 30-mesh	5.32	18.85	0.03	0.11
On 40-mesh	9.77	34.56	0.12	0.40
On 60-mesh	15.94	56.42	1.13	4.01
On 100-mesh	13.96	49.42	7.43	26.28
On 150-mesh	12.29	43.50	18.42	65.22
Through 150-mesh	42.72	151.25	72.87	257.98

The daily tonnage of sands passing through the tube-mills is about 230 tons, or about 77 tons per mill.

It will be seen from the above grading that the mills are doing very good work, practically all the material of 30,- 40- and 60-mesh size having disappeared.

An additional tube-mill is being installed, and when completed either the coarser portion—up to 100 mesh—will be sent to this mill, or coarser screens, say 15-mesh, will be used on the stamps. It is a matter of experiment to determine which will give the better commercial result—finer grinding for increased extraction, or larger milling-tonnage. In addition to the benefit of increased tonnage by the substitution of 20-mesh screen in place of 40-mesh, the tube-mills have favorably influenced the extraction, for the reason that before their use the combined sand and slime residues assayed 31 grains of gold per ton, representing an extraction of 89.8 per cent., but after installation the combined residues assayed 24 grains of gold per ton, representing an extraction of over 92 per cent.

A most important result of grinding in tube-mills has been the effect on the slimes. A large proportion of sand is ground so fine that it passes the *spitzlutte* with the slime, the result

being that the slime is more easily treated either by the filter-presses or the vacuum-process. This result is shown by the time required for filling and washing the presses, which can now deal with 30 per cent. more slime than in treating slimes from stamps on 40-mesh size.

The cost of running the tube-mills, per ton of sand passed through the mills, is:

	Cents.
Power,	12.5
Flints and liners,	14.0
Labor, repairs and stores,	1.5
Total,	28.0

or, on the total mill-tonnage, 18.2c. per ton of ore crushed.

The chief benefits derived from tube-mills at Waihi are:

1. Increased extraction, amounting to about 36c. per ton on the whole of the ore crushed.

2. Increased tonnage of fully 36 per cent.

3. A saving of 75 per cent. on the cost of screens. The 20-mesh now used costs less and lasts considerably longer than the 40-mesh previously used.

4. Amalgamation improved by from 5 to 7 per cent.

5. The slime, owing to the contained fine sand, is more easily treated.

The reduction in milling-cost due to the tube-mills is fully 12c. per ton on the total tonnage. This, together with the 36c. improved extraction, represents a total increased saving of 48c. per ton, or $169 per day on the 90 stamps.

When it is considered that, in addition to this result, the bullion production is augmented by the product from the extra 94 tons per day, it must be conceded that tube-mills have proved highly successful at Waihi.

Owing to these results at the "Waihi" mill, arrangements are now in hand to equip the "Victoria" mill of 200 stamps with a plant of at least 9 tube-mills.

By the improved methods now coming to the front for handling slimes, and the economical grinding which is obtained with tube-mills, it is my opinion that the time is not far distant when such ores as those at the Waihi mine will be treated mostly in the form of slime.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Butters Slime-Filter at the Cyanide Plant of the Combination Mines Company, Goldfield, Nev.

BY MARK R. LAMB, GOLDFIELD, NEV.

(New York Meeting, April, 1907.)

THE treatment of slime is of special interest to those engaged in cyaniding gold- and silver-ores. The usual practice is to make as small a percentage of slime as possible. In many instances the slime is given no treatment, but is impounded in dams in the hope that the future will develop some method of economically treating this product. The filter-press was the first step upward from ordinary decantation, but, on account of heavy labor-charge and high cost, its use has been limited to high-grade material.

The slime at the Combination mill at Goldfield averages perhaps $20 per ton, and although the values are quickly dissolved the filter-press installation was not entirely satisfactory, resulting in the erection of the canvas-cell filter, developed by Chas. Butters and his staff. This filter is a great improvement over the filter-press, and the following description of it will be of interest to those engaged in treating slime produced in crushing ores, especially in view of the fact that, by the use of this filter, slime can be treated at a lesser cost and with a higher percentage of gold- or silver-extraction than in the ordinary treatment of sand; and, moreover, the initial outlay for an all-sliming plant is less than that for the ordinary sand- and slime-plant.

The economy of construction of the Butters filter-plant is clearly shown in Figs. 1 and 2, which illustrate the 20-frame filter of 40 tons capacity, now being installed by the Nevada Goldfield Reduction Co. In this construction the slime-pump is so connected that it can pump to or from either tank or the filter by changing the valve-settings—a combination which is necessary in this particular installation, since sufficient fall is not available for filling and discharging the filter by gravity.

Ordinarily, a slime-plant comprises: a filter-box with frames

or cells; two tanks of double the capacity of the filter-box, for slime and water, respectively; a "wet" or "dry" vacuum-pump, or other source of vacuum; a centrifugal slime-pump; and a series of agitation-tanks, which also provides storage for

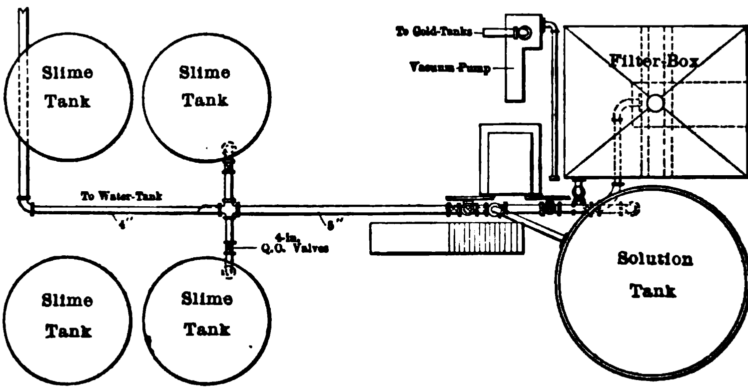


FIG. 1.—THE 20-FRAME FILTER OF THE NEVADA GOLDFIELD REDUCTION CO. (Plan.)

the slime. With regard to the economy in labor required to operate the Butters filter-plant, 500 tons of slimes, or even more, can be treated, filtered and discharged by one man per

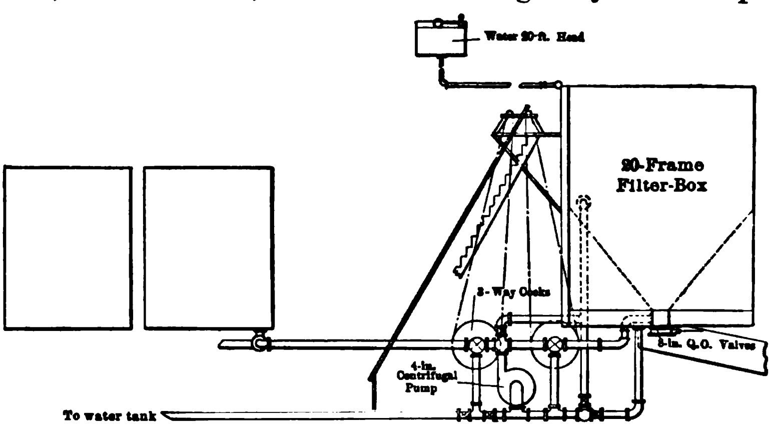


FIG. 2.—THE 20-FRAME FILTER OF THE NEVADA GOLDFIELD REDUCTION CO. (Side Elevation.)

shift—a remarkable gain as compared with ordinary practice in filter-pressing.

Where the filter is installed to replace treatment by decantation, no extra tanks are required, and the necessary additions are merely the filter and a source of vacuum. Furthermore,

the unused settling- and treatment-tanks can be used as treatment-tanks, thus increasing the time of treatment, if desirable, and also increasing the capacity of the plant.

The cycle of operations is as follows: The slime, after agitation in solution the required time, is pumped into the filter-box. As soon as the latter is full the filter is connected to the source of vacuum and the gold-solution drawn from the pulp through the canvas of the cells, while the slime forms a layer on the outer surface of the canvas. While the slime-cake is being formed, the filter-box is kept full of slime-pulp by pumping it in as fast as solution is drawn out through the frames. When this layer is of suitable thickness (which depends on the permeability of the slime) the vacuum is reduced to a pressure barely sufficient to hold the slime in place, and the pulp still in the filter-box is returned to its storage-tank. The centrifugal pump is set to fill the filter-box with water, the vacuum is raised, and the slime-cake is washed. This water which passes through the filter is sent to the gold-tank. When desirable, the slime can be given a wash with solution before washing with water. This will be done at the Nevada-Goldfield plant. When all dissolved metal is removed from the cake it is dropped from the canvas by merely breaking the vacuum and turning water or water and air into the cells under a pressure of about 10 lb. per sq. in. A period of 5 min. suffices to drop the slime. Surplus water in the filter is then drawn off, if the saving of small quantities of water is desirable, and the bottom discharge-valve opened. The slime, containing from 20 to 40 per cent. of moisture, is discharged in less than a minute.

The time required for the treatment of one lot of slime is about 3 hr., depending upon the thickness of the cake, the size of the slime-pump, and the permeability of the material—all matters which can be determined in advance. The filter is used six or eight times in 24 hr. Correctly speaking, the slime is not treated in the filter, since agitation and extraction of the values take place before the filter is reached. In other words, the filter is used solely to displace the metal-bearing solution. In Mexico, the filter is handled by one Mexican peon per shift. These peons learn quickly and are entirely satisfactory.

One of the most important and vital features of the filter is the fact that the regulation of the thickness of the layer of

slime depends upon its permeability. Thus, if fine sand is mixed with slime, it tends to collect on the bottom of the center cells (which are directly over the inlet from the pump) in a proportionately thicker layer, thus causing all parts of the layer of slime to be equally washed.

Compare this ideal automatism with the action in an ordinary filter-press, in which the slime and sand have a decided tendency to classify in the frames, with the result that the cake will show a larger proportion of sand in the lower half. This settling, of course, makes it necessary to wash the charge longer than would be the case if the cakes were homogeneous throughout. In many instances the entire volume of wash-solution passes through the coarser material in the lower portion of the frame of the filter-press, and the fine slime is not washed. This results in a large volume of wash-solution, besides loss of cyanide and dissolved metals.

The economy in time for complete displacement by the Butters filter (from 15 to 20 minutes, see Table I.) is plainly evident when compared with the usual practice, using a press or by decantation. The Virginia City plant of Chas. Butters & Co. is now treating ores from Tonopah, the slime of which settles very slowly. The pulp is brought to the plant with about 100 parts of water to one of slime, which condition will be changed shortly, but which now makes a secondary de-watering filter necessary. This latter device works well, and but for it the slime could not be treated except with a large loss of solution.

According to the paper by Charles Butters and E. M. Hamilton, entitled "On the Cyaniding of Ore at El Oro, Mexico, Dealing Principally with Re-Grinding of Sands,"[1] describing practice at El Oro, Mex., slime can be made of sand at a cost of $0.53 gold per ton. The cost at the Combination mill is a little less than this figure.

It is rarely the case that the difference in value between sand and slime tail-assays would not exceed this amount, and including the occasional (?) slimy sand-tank, with which the cyanider must contend, calculation will show that many plants could largely increase profits by sliming the entire product.

Fig. 3 is a view in the Virginia City plant, showing the elec-

[1] *Institution of Mining and Metallurgy*, vol. xiv., pp. 3 to 46 (1904–05).

FIG. 3.—THE 90-FRAME FILTER-BOX AND ELECTROLYTIC PRECIPITATION-VATS AT VIRGINIA CITY PLANT.

FIG. 4.—SLIME-PUMP, THREE-WAY COCKS, VALVES AND PIPING AT COMBINATION PLANT.

FIG. 5.—END-VIEW OF LOWER HALF OF FILTER-BOX, WITH GEARED CENTRIFUGAL PUMP AT THE SIDE, COMBINATION PLANT.

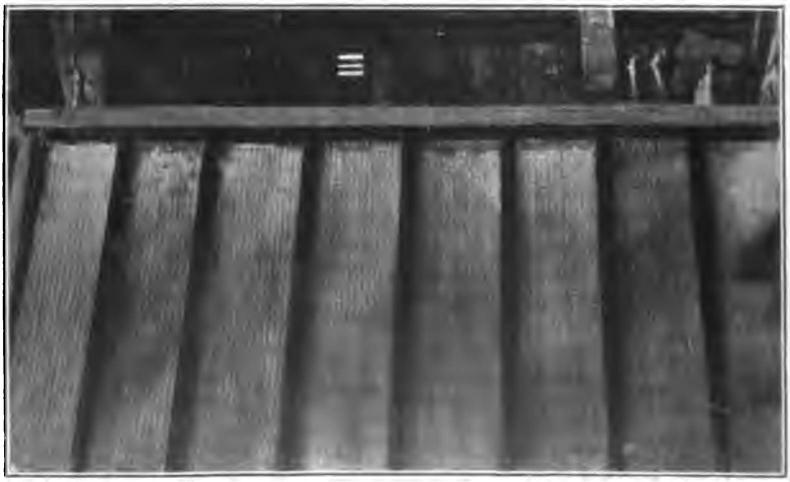


FIG. 6.—ONE LEAF OF THE FILTER, SHOWING REINFORCEMENT BY STITCHING, COMBINATION PLANT.

trolytic precipitation-vats in the foreground, directly in front of a 90-frame filter-box, which has a capacity of from 150 to 200 tons per day.

Fig. 4 shows the slime-pump, three-way cocks, quick-opening valves and piping at the Combination plant, which arrangement, as previously explained, is necessary only where sufficient grade is not available.

Fig. 5 shows the end-view of the lower half of the filter-box, and, at the right-hand side, the geared vacuum-pump.

Fig. 6 shows one leaf of the filter, which has lines of stitching in order to resist the internal pressure.

Fig. 7 is a perspective view of a plant of 100 tons daily capacity, comprising the filter-box, the slime- and water-storage tanks above, the slime-storage tank below, the vacuum-drum connected to the filter-leaves and to the gold-sump, and the gold-solution and slime-pumps.

Fig. 8 is a detail view of the filter-box shown in Fig. 7, with filter-leaves in position, some shown in section, and some removed.

The list of tests, made to show results which were being attained at the Combination plant,[2] is given below.

It should be explained that "water" wash was, in reality, solution assaying $0.60 per ton, which would otherwise be waste solution. This water, as it is drawn through the slime-cake, does not go to the zinc-boxes, but is used to replace the weak wash, which is precipitated. The weak wash assayed $4.02 per ton.

TABLE I.—*Solutions from a Cake* 1.25 *In. Thick.*

Weak Wash. Time.	Value Per Ton.	*Water Wash.* Time.	Value Per Ton.
After 2 min.,	$12.22	After 5 min.,	$3.66
After 4 min.,	12.20	After 10 min.,	3.62
After 6 min.,	11.89	After 15 min.,	3.12
After 8 min.,	11.96	After 20 min.,	0.60
After 10 min.,	11.40	After 25 min.,	0.60
After 12 min.,	10.90	After 30 min.,	0.60
After 14 min.,	8.90		
After 16 min.,	6.82		
After 18 min.,	4.76		
After 20 min.,	4.46		
After 22 min.,	4.26		
After 24 min.,	4.12		
After 26 min.,	4.10		
After 28 min.,	4.02		

[2] *Engineering and Mining Journal*, vol. lxxxi., pp. 1236 to 1238 (1906).

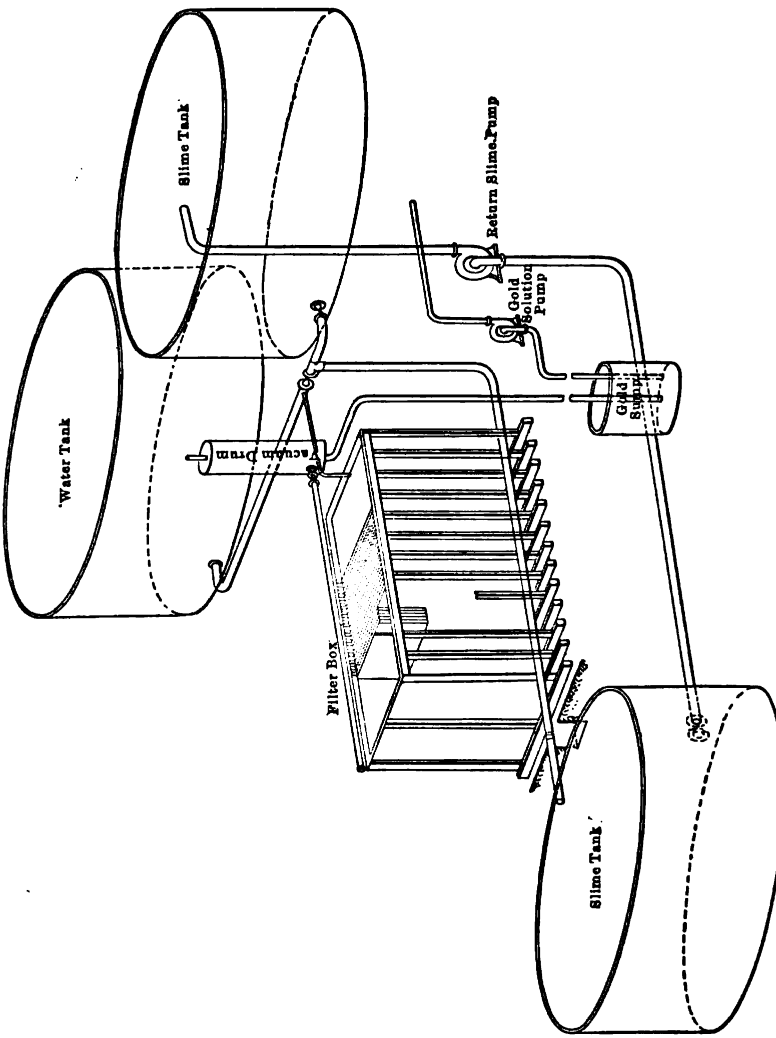


FIG. 7.—VIEW SHOWING ARRANGEMENT OF A 100-TON SLIME-FILTER.

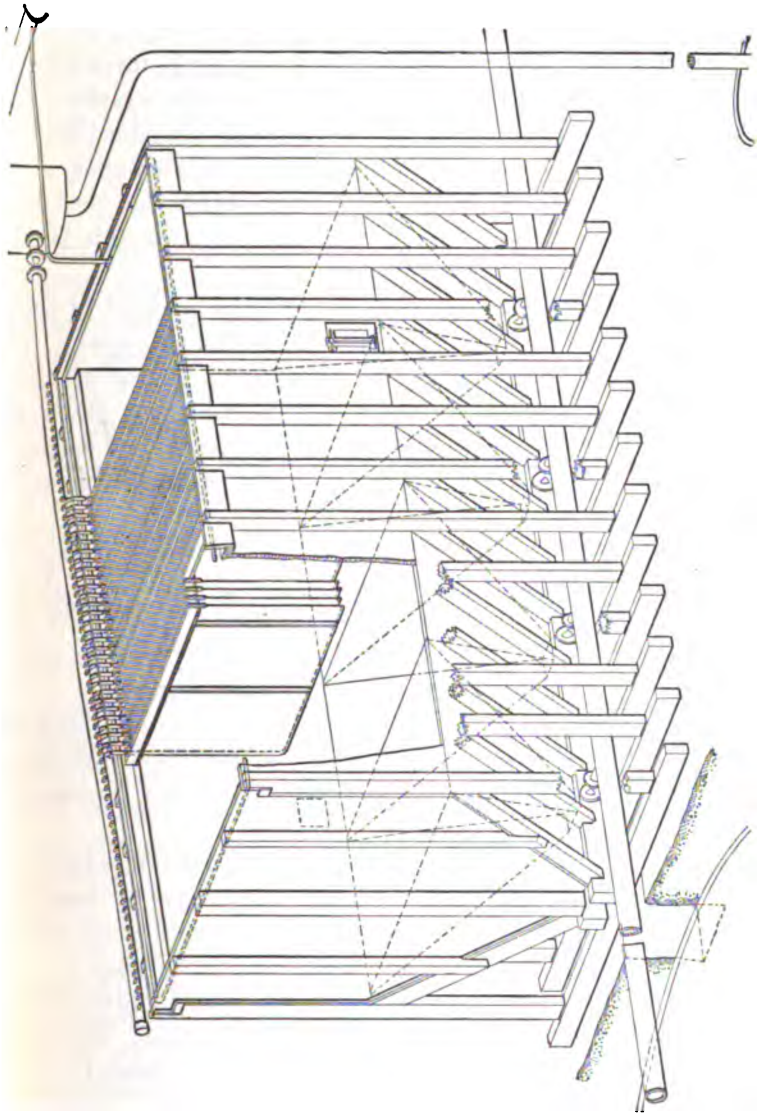


FIG. 8.—DETAIL VIEW OF FILTER-BOX.

The practice at the Combination mill is to wash from 16 to 18 min. with solution and the same length of time with water.

The ordinary slime-settling device, whether tank or spitzkasten, rarely produces a product with less than 60 per cent. of moisture, and in many cases the proportion is three or four to one. This water must necessarily dilute the cyanide solution added to the slime, or, in case cyanide is added to the slime without further addition of solution, this solution, after precipitation, must be run to waste. Of course, the ideal way is to mill in solution, though for other reasons this is not always desirable.

When milling in water, by a proper arrangement of pipes and valves, and by providing a filter of sufficient capacity, the settled slime can be dried to any economical degree of moisture; and by filling the filter-box with solution the slime can be pulped again by means of the centrifugal pump and returned to the agitators, thus avoiding the necessity of making solution which must be run to waste.

As an example of what can be done, 100 tons of slime, if treated without removing the water, will cause the loss of about 75 tons of weak solution, containing about 0.8 lb. of KCN per ton, or 60 lb. If the Butters filter is used, this loss can easily be reduced to 8 lb. or less, without additional expense.

Particular attention should be paid to the thoroughness of the wash. After 20 min., if pure water be used, the wash-water from the slime at the Combination mill shows no measurable quantity of cyanide.

The quantity of solution made by washing is much reduced in volume when compared with the amount necessary for washing a filter-press charge. In fact, the wash-water will about make up for evaporation losses when ore is milled in solution.

Experiments are now under way with a view of doing the entire treatment on the filter, thus saving tankage and time. These experiments will only succeed with ores such as that treated at the Homestake slime-plant, where extraction from slime is almost instantaneous. Such treatment would not succeed with a silver-ore, for example, where long agitation and aëration are required.

I feel confident that this filter will be the cause of many plants abandoning entirely the treatment of sand, thus reducing the cost of installation, depreciation and operation, and increasing the capacity and the extraction.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Fluorite and Barite in Tennessee.

Author's Postscript to a Paper on "Lead- and Zinc-Deposits of the Virginia-Tennessee Region," *Trans.*, xxxvi., 681 to 737 (1906).

BY THOMAS L. WATSON, BLACKSBURG, VA.

MY thanks are due to Mr. Frank Firmstone, Easton, Pa., who has called my attention to the statement in my paper[1] that "Barite, fluorite and quartz, though not observed in the Tennessee area," . . . as possibly misleading to the reader, if construed to mean that such a discovery had never been made. Mr. Firmstone is correct in assuming that this statement referred only to the study of the worked areas of the metallic ores, especially zinc, made in the course of the survey upon which my paper was based.

The occurrence of barite and fluorite with lead-ores in Tennessee was reported by Prof. Safford,[2] in 1869, and by Safford and Killebrew,[3] in 1887, with the further statement that about 1,000,000 lb. of barite were annually mined in Greene, Washington and Jefferson counties, Tenn., and that considerable deposits occur also in McMinn, Smith and other counties. It is also noted that the barite "usually occurs in veins, associated with galena." The present worked areas of barite are, however, distinct barite propositions, without workable quantities of either lead or zinc, so far as mining operations have gone, and the areas are more or less removed from the present areas of zinc-ores.

Mr. Firmstone informs me also that, in 1892, he observed, in the magnesian limestone at Watauga Point, in Carter county, on the left bank of the Watauga river, a little below the mouth of Buffalo creek, small quantities of galena and some fluorite.

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[1] *Trans.*, xxxvi., 686 (1906).

[2] *Geology of Tennessee*, by James M. Safford, A.M., Ph.D., p. 224, Nashville (1869).

[3] *Elementary Geology of Tennessee*, by James M. Safford and J. B. Killebrew, pp. 140, 198, Nashville (1887).

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Gas-Engine Practice.

A discussion of the Papers by Prof. H. Hubert, Liège, Belgium; Mr. Tom Westgarth, Middlesbrough, England; and Mr. K. Reinhardt, Dortmund, Germany, presented at the London Meeting, July, 1906, and printed in *Bi-Monthly Bulletin*, No. 12, November, 1906, pp. 910 to 930, 971 to 987, 1037 to 1163.

MR. ADOLPH GREINER, Seraing, Belgium:—I have nothing special to add to Professor Hubert's paper except to say that there are some little things that it would be well to have corrected when the paper comes to be published. In dealing with the thermal efficiency of the engine, you will find that the 29.84 per cent. was a very high one. Professor Hubert has forgotten those engines built under the Cockerill type, but he has referred to them in Appendix II. At our works at Cockerill we have built 63 engines, giving 63,000 h.p., and the other companies who have received licenses have built 113 engines, making 103,000 h.p., and aggregating 176 engines and 166,000 h.p. Eight years ago I had the pleasure of giving to the Institute the results obtained up to that time. Since then a good many engines have been constructed. In 1898 I thought a blast-furnace producing 100 tons of pig iron would allow 3,000 h.p. Professor Witz and Professor Hubert show that with the same production of pig the new engines take 3,800 h.p. out of the gas. At present at Cockerill we make 700 to 800 tons of pig iron per day, and we hope to have 26,000 h.p. in a few years. At present we have only half of that in gas-engines, but we hope to have in five or six years all the gas out of these furnaces to the number of 25,000 or 26,000 h.p.

MR. TOM WESTGARTH, Middlesbrough, England:—My contribution is not a paper in the ordinary sense of the word, because I am sure you will agree with me that what I have written is only supplementary to the other two papers. The notes are schedules of the larger-size gas-engines built by the engine-makers, of 500 h.p. and upwards. If you look at the schedules you will find that in England gas-engines have be-

come quite ordinary motors for a good many purposes. It was at first thought that gas-engines were troublesome, and ill-adapted for general purposes, that they were not of much use; but you will see now from the schedules that they are being employed for driving dynamos, working blowing-engines, and driving rolling-mills, tube-mills, air-compressors, cement-mills, paper-mills, electrolytic work, and even cotton-mill work, mine-fans, and so on. I do not think that it needs any argument to show that the gas-engine has come to stay, and that it is doing a great variety of very useful work. Another point which I would like to call your attention to in the schedules is the different kinds of gas being used. The primary object of this type of gas-engine is to use gases which hitherto have been wasted, but which a few years ago suddenly attained great value, because of the way in which they could be utilized with advantage in running gas-engines. In addition to blast-furnace gases, coke-oven gas, and various kinds of producer-gas, even that from bituminous coal has been used to work gas-engines of large size. I am sorry that when I asked Messrs. Beardmore for the particulars of their engines they did not send any particulars of their vertical marine-engines, because although that point is not particularly interesting to us as iron and steel makers, it is interesting to engineers, and has an important bearing on the question of the development of gas-engines. Messrs. Beardmore have already published some particulars of their 500 and 1,000 h.p. vertical marine-engines, and I hope that some of their people will tell us something of the success of their engines when they have got them to work, and particularly as to the success or otherwise of the reversing engines. That is one of the great problems—viz., how to adapt them successfully to marine work. They might be useful also to some of our members for driving rolling-mills. Then I added a few things in the paper as to how much is done in this direction in this country. The only other point is the question of cleaning the gas. I fear, as a builder of gas-engines, that a good many of our members connected with iron- and steel-works are troubled about the difficulty of getting gas-engines to work properly at first because of the imperfect cleaning of the gas. You will see by the illustrations given in the paper that there are many people who have been working and clean-

ing gas, and many of these users have obtained very satisfactory results. I notice in the German paper it was stated that gas is cleaned to the extent of 0.02 g. of impurity. I telegraphed to Mr. Cochrane yesterday, and the result was that he replied that ordinary blast-furnace gas was cleaned to 0.0025, which is as clean as this room, or possibly cleaner; as we happen to be in London. The figures I received from Mr. Cochrane were 0.0025, 0.0026, 0.0033, 0.0037, 0.0025, 0.0024, 0.0024, 0.0019, etc. That justifies my statement that gas can be cleaned to 0.02, as described in the German and in my own paper. Therefore I hope you will understand that the great initial difficulties in cleaning the various waste-gases in gas-engines have effectually been overcome.

Mr. Greiner:—Mr. Theisen has built an apparatus of a special sort which is the type shown in Mr. Westgarth's paper. Our experience at Seraing some seven or eight years ago was that Mr. Theisen was wrong when he said that the air was warmest when it entered the apparatus, and that it gave the best results. That is not right. The air must come into the Theisen apparatus and generally into all centrifugal apparatus as cool as possible, and the reason is that when air is heated it holds more steam or vapor, and the more vapor there is in the air the more dust there is in it. For that reason it is better to cool the gas before it goes into the Theisen apparatus, and all centrifugal apparatus. We could clean 4 or 5 g. of dust quite well, but the result would be that after a few days or a few weeks the apparatus would become so very full that it would be difficult to clean it at all, because the dust is put on the ledge. Our experience is that the cooler the air the better it is for entering into the Theisen apparatus, and it gives the best results that way. That has been pointed out by Professor Osann, and it agrees absolutely with our experience at Seraing with the Theisen apparatus itself.

Mr. Julian Kennedy, Pittsburg, Pa.:—We in America are only beginners in the gas-engine business, so that we can have very little to say about it, although we hope to learn a great deal about it. We all appreciate that the great thing to be learned now, perhaps, is the easy and thorough method of

cleaning gases which have to be worked up. We have had very little experience of it in America. The Lackawanna Steel Co. are about the only people who have done anything in gas-engines in America. We had some trouble at the start, as was only to be expected, but we are now achieving a great deal of success with our gas-engines, and the general feeling is that the era of this style of motor is dawning with us.

DR. R. W. RAYMOND, New York, N. Y.:—After more than 25 years of service as the Secretary of the Institute, I have learned that my knowledge of contemporary progress depends largely upon the members of my Society. If I do not get any papers on gas-engines, I may not know much about gas-engines; but when the members of the Society begin to talk them up, then I realize that a new era has dawned. In the Institute of Mining Engineers, which includes blast-furnace managers, this is beginning to take place. American ironmasters are coming to the gas-engine. In spite of the wealth of our rich ores, our half-developed mineral resources, and our youthful strength as a nation, we are beginning to learn that heat and the materials that yield heat must be economized. We are not so rich that we can go on wasting; and if we succeed at all in maintaining the position to which we have somewhat suddenly jumped in this branch of industry, it must be done by carrying our book-keeping out to the third place of decimals, as is done in the papers read to-day, and by saving as well as spending. I believe I may say for American metallurgists, and their great individual or corporate combinations of capital, that they have not only heaped up sums in investments which staggered the imagination, but have also made a single dollar go further by putting a great many individual dollars together;—which is indeed the only justification for our large accumulation of capital. Moreover, it is but fair, in an age when "trusts," and "combines," and great corporations get all the blame they deserve, and more, from other people, that those who have profited by them should speak an honest word in their defense. I would therefore say that in America, at least, as I presume also in England, the great concerns which install such engines as have been described here are the concerns which employ the

best scientific aid, pay the best wages, do the best work, and most effectively serve the human race.

PROFESSOR WM. KENT, Syracuse University, Syracuse, N. Y.: —We have been greatly pleased in finding how the Germans are leading the way and the English also are beating the Americans in the adoption of gas-engines, but it seems to me to be a little maneuver of the Americans to watch how others would do the work and thus to get the value out of the experience of others without the expenditure of their own money. It was found in the days of street-car transportation in America that the man who was first in substituting electric transportation for the mule was the man who lost the most money, and that those who waited four or five years until those bold, enterprising persons had lost their money, and gained their experience—those who held on to the mules—ultimately got the money out of the other men's experience. So Americans have saved an immense amount of money by not building gas-engines. Now they are going to build gas-engines with licenses from the German and the British patentees, and they are going to do just as good work as the Germans. The Germans have developed the gas-engine and the cleaner, but there is a good deal yet to be done. The field for the gas-engine is, of course, to utilize the waste-gases of the blast-furnace; but the blast-furnace produces gases of irregular quality and quantity, and the demand of the blast-furnace for power is also irregular. What we need is a governing-apparatus with which to provide all the gas-engine plant, and that is suggested in Mr. Reinhardt's paper, in which auxiliary producers are mentioned, using coal to furnish the regulating-supply, and to make up for the irregular demand. In the future there is going to be a large plant near a large city where iron-works are situated, and this will supply the electric light and the electric power to the city. Such a plant would have to have reserve gas-producers using bituminous coal direct, and burning up all the hydrocarbons in the producer itself. The producers mentioned in the paper (there are at least two of them patented in America, of one of which I happen to be the patentee) would do that. I believe that practice in the future will take the form of regulating the

supply for the gas-engine plant by having a surplus available derived from the auxiliary gas-producers, and the installation will thus be complete for the utilization of blast-furnace gases and for the development of electric power for rolling-mills and for power purposes in the adjacent town.

MR. E. J. DUFF, Liverpool, England:—All of us who have been interested in the development of gas-power and the new method of gas-production by the recovery of ammonia must have read Mr. Reinhardt's paper with great interest and advantage. It is a paper that goes very thoroughly into the matter and brings the subject right up to date. I will confine my remarks to one topic, which is dealt with on page 9[1]—viz., coke-oven gases. About seven years ago I was called upon to erect some coke-ovens at Widnes. I found that when the ovens were put to work they produced a surplus of gas; that is to say, that after the gas was put out of the ovens and burnt from the ovens there was still a surplus of gas which went to waste. There was also a good deal of surplus steam raised from waste-gases—that is, from the burning-gases; and after they had used what was required from the recovery-process there was still a surplus. I set to work to discover how to utilize the surplus gases after the coke-ovens had been fired. Eventually we decided to adopt gas-engines to utilize the gas to drive dynamos, and to run electric furnaces by the dynamos for the production of calcium carbide. That worked extremely well from the start. We calculated that we had enough gas to run 500 h.p. I applied to various makers for 500-h.p. engines, and none of them would build one. That was only seven years ago. I adopted 250-h.p. engines, the largest built in this country then. Very little scrubbing and washing was required for that gas, and the only alteration that I found necessary after commencing to run the engines was the insertion of a little box, 2 ft. square, of iron oxide, to take out a trace of sulphur and cyanide. In that connection I find that many coke-ovens are working in this country producing sufficient cyanide to make it worth while to recover it. Then, again, with regard to the surplus steam coming from those ovens, Mr. Reinhardt said, (*Bi-Monthly Bulletin*, No. 12, November, 1906, p. 1042): "In

[1] Preliminary pamphlet edition of the Iron and Steel Institute, July, 1906.

the new regenerative coke-ovens the waste heat is utilized for pre-heating the oven itself, whereby there is an economy in gas, and a greater excess of gas is available for driving gas-motors." That, I think, is one of the best things for the recovery, inasmuch as it takes away that surplus steam, and it gives the excess of gas which we can utilize in gas-engines. Mr. Westgarth in his paper referred to the nature of the gas used in the engines tabulated in his paper, and he has thought a paper on gas-engines would be incomplete without reference to gas-cleaning appliances. In this connection I would like to mention that the twenty-eight engines given in Table I. of the paper, with a total capacity of 82,600 i.h.p., are all working on some form of Duff producer-gas. I would also mention that Beardmore & Co. have built, and are building, producers of a total capacity of 100,000 h.p., all of which clean the gas and recover from it the by-products, the sulphate of ammonia, in sufficient quantity to pay the whole of the coal-bill. The greatest credit is due to Mr. Beardmore for his courage and ability in experimenting on such a large scale, and not only for undertaking the extensive use of gas and electric power in connection with the general work of shipbuilding and engineering, but also for applying the system to rolling-mills and steel-melting furnaces under the exacting and somewhat hard service required in steel-works. This has all been accomplished since I designed Mr. Beardmore's plant four years ago. None of these papers on gas-engines, so far as I am aware, have referred to a very important installation of gas-power which has been erected and put to work at Madrid, in Spain. The gas-plant is my own design, and the engines are of the Nürnberg pattern, of 2,000 h.p. There are six engines of 2,000 h.p., with a total capacity of 12,000 h.p. One of these engines has made a record run of practically six months, and there is no trouble with tar.

MR. JAMES HAMILTON, Coatbridge, England:—The first feeling of manufacturers in this country on reading the papers is that of envy at the great development and the great progress which the Germans have made. It is not so much the fault of the British gas-engine makers as of the British gas-engineers. I think that the gas-engine in this country, now that it has got through its period of initiation, is going to develop more

rapidly. It is a pity that the ironmasters have not considered the merits of the engine more, because there are great savings possible, and great savings have been effected where it has been tried. British gas-engines have not developed along quite the same lines as the German engines. The German engines have been designed chiefly with a view to increasing the maximum power, and not so much with a view of increasing the economy. The four-cycle engine described by Mr. Reinhardt is certainly more economical than the two-cycle engine; but that is not altogether the reason for its being adopted in Germany and in Belgium. In this country a greater amount of work has been done with producer-gas than with blast-furnace gas, and in consequence the English engines have been developed rather with a view of economy, because when we get the blast-furnace gas for nothing a little extra consumption is not of so much consequence as when we have to pay for the fuel to produce it. In a blast-furnace gas-engine the saving as compared with a steam-engine is about five to one—that is, five times as much power from the gas-engine as from the steam-engine with the same amount of cost. In the producer-gas engine we do not get so much saving because there is the question of the efficiency of the producer to be deducted from the result. We have to combine the producer and the gas-engine, and the efficiency of the whole thing is the combined efficiency of the two. The Continental designs have been to a certain extent adopted in this country, and are now working in competition with British designs, and no doubt the future will decide which type is the best. Each has its merits, but so far the British designs have held their place in competition with the Continental designs that have been taken up and made in this country. As a gas-engine maker I must thank the gentlemen who have so liberally placed the results of their experience and knowledge at the disposal of the Institute. They have conferred a great favor on the iron- and steel-industry generally, and the gas-engine making industry in particular, and I am sure we owe the authors our best thanks.

MR. A. T. TANNETT-WALKER, Leeds, England:—I am afraid I have nothing to add to the discussion; but as one interested in gas-engines, and who, some thirty-four years ago, saw a good

deal of the development of these motors, I would like to express my indebtedness to those who have read the papers. I consider the paper of Mr. Reinhardt quite a treatise on gas-engines, and we are all indebted to Professor Hubert and to our valued friend, Mr. Greiner, for the information they have given to us. We were told some eight years ago to what perfection we could work by blast-furnace gas-engines, and I have taken great pains to see whether they are perfect, but I find there is a great deal to do to make them perfect. As our American friend has said, those who stuck to their mules have kept their money. But, of course, if there were no pioneers we would have no great inventions brought to perfection. There is one thing I must take exception to—viz., the remark of my American friend (Professor Kent), that all the developments have been made by the Germans. The Otto gas-engine was brought to this country and offered to my father, the late Benjamin Walker, who, however, I am sorry to say, did not take it up; but Crossley Brothers took it up and, to their credit be it said, they have developed it with certain inventions, such as the valve-gear and other innovations, the result of experience. Therefore I say that the Germans have largely developed gas-engines, but they were not the originators, they were not the pioneers of gas-engines. We must, in fact, give the old country, the fossil that Sir James Kitson referred to, the chief credit, because the old country has held its place even in the manufacture and the development of these modern motors.

Mr. Mark Robinson, London, England:—I am afraid I have nothing very useful to say. I have been engaged over the design and construction of large gas-engines lately, and it has certainly proved itself to be a very interesting subject. It is a subject about which there is a great deal to learn, and I can cordially indorse the remarks of the gentleman from the other side of the Atlantic who has said there is a great deal of loss upon them. The German paper seems a most valuable one, and it is a mine of information. All the papers are very useful, and we owe great thanks to the authors for them. But there is one subject which these papers do not touch upon, and I wish they did. It is natural to keep the eye on the engines to use blast-furnace gases when addressing the Iron and Steel Institute;

but allusion has been made to the use of the gas-engine for other purposes, and, of course, it is used for producer-gas. When the company with which I am connected took up the gas-engine it was almost entirely for the using of producer-gas and for the driving of dynamos; and from the best information we can gather we believe there are difficulties when it is working the producer-gas unless there is some very special arrangement for cooling the engine. I do not think that any allusion is made to the scavenge in any of those papers. I believe the great makers of the four-cycle engines, Messrs. Cockerill, do not use the scavenge at all, and think it unnecessary. I believe it would be a very good thing for English designers to get some pronouncement from the great masters on the Continent as to whether the scavenging is necessary or not. On the other hand, they are almost always working with blast-furnace gas, which is very much cooler and is not liable to lead to pre-ignition and other troubles, as we might suppose producer-gas to be. But still it was stated that Continental gas-engines are worked with producer-gas. If they are worked with gas of as much calorific power as producer-gas is worked in this country, and they do not give so much trouble, and work successfully without a scavenge, it is highly desirable that we should know those things upon the highest authority. I wish that in some future paper on the subject this might be brought out by some of our German friends.

Professor Turner, Birmingham, England:—I cannot speak as an authority on large gas-engines, as the gas-engines with which we have to do at our University at Birmingham are small. All that we have is an installation of the Mond gas-plant for engines, the largest being 150 h.p., used for the production of current for various purposes throughout the University. I need scarcely say that we have had no trouble with those engines, and they work with the greatest possible satisfaction. But the Institute is interested in the question of large gas-engines in connection with the manufacture of iron and steel, and many of us have been wanting information in connection with the development of these engines. The information is not that which we could get at the University, and it

could only come from practical men. We are very much indebted to those who have been good enough to give it to us.

Mr. B. H. Thwaite, London, England :—I have made a few notes on these papers. It is impossible to refer to them otherwise, and if the members do not mind I will read my notes, as they would be more definitely expressed than in a speech. In the first instance, I congratulate the authors of the three papers in providing a more or less complete record of the progress in the use of the blast-furnace gas-engine and its displacement of steam, and of the evolution of the high-power-capacity gas-engine. Apparently the energy that is already being developed is close on half a million horse-power. We should not allow an opportunity to pass without an expression of admiration for the splendid enterprise shown by engine-builders and ironmasters in Germany in risking the capital involved in raising the unit-power-capacity of gas-engines. The other day on formulating an electric-power generating scheme I had no hesitation in specifying for 10,000 i.h.p. with multiple engines. I am glad that in the distribution of the palms the claims of our country have not been overlooked; but when the authors write again on the historic part, and especially in the light of the truth that is now being admitted without hindrance, I hope they will carefully read patent document No. 8,670, of May, 1894, also Professor Watkinson's paper read before the West of Scotland Institute on March 15, 1895, and the discussion thereon, with the remarks of Mr. Riley, the then chairman. If they do so they will then agree that the word "simultaneous" is absurd; and the reference to his propositions in *Le Rappel*, *Le Figaro*, and other French newspapers in 1885 was rather contradictory to the statement made by Mr. Hubert. To say that "the investigations were independent of Thwaite's experiments, which were not generally known on the Continent," was incorrect, for the experiments were practically the same. The English were first in the field. In my paper read before the British Iron Trade Association in 1898, I gave a thermal comparison between steam-power efficiencies of the ordinary iron-works type of the blast-furnace gas-engine as follows: Heat expenditure to secure 1 h.p. per hour of energy in steam iron-works plant equals B.t.u. ÷ 43,300. The blast-furnace gas-engine

at that time developed the same power of one-fourth, or 10,828. To-day we can rely upon securing a still higher result of efficiency. Mr. Hamilton will guarantee to develop an indicated horse-power with an expenditure of 8,000 B.t.u., and so will Mr. Thomas Westgarth. I have explained in the *Times* that one reason why I have sought to develop power with gases of low calorific value is my recognition of the effect on gas-engine limits of efficiency of the law of increase of specific heat with increase of temperature. In the selection of such a gas I decided in favor of carbon monoxide, and the exclusion as far as practicable of hydrogen gas, for various reasons. A gas of the chemical constitution of blast-furnace gas gives me the power-gas I want, and you see the justification of my reasoning in the records of the three papers read to-day. It is pleasant and refreshing to find that Mr. Reinhardt's idea of a standard system of cleaning blast-furnace gas is practically that of the Thwaite system. Looking back, it is certainly amusing to remember, although at the time the statements were made vexation and indignation were the dominant feelings, how we were once told that no cleaning of the furnace-gas was required, in distinct contradiction of my own experience and the formulæ of my 1894 patents. Mr. Reinhardt referred to a standard type of purifying-plant for blast-furnace gas (*Bi-Monthly Bulletin*, No. 12, November, 1906, p. 1045), and observed: "The gases on leaving the blast-furnace are led through a series of so-called dry purifiers, and thence through long pipe-lines into the coolers or scrubbers, and from these into the so-called centrifugal purifiers (Theisen apparatus or fans with water-spray). After leaving the above plant the purification of the gas should be complete, so that before being admitted into the engine the gas has only to be dried in filters or in capacious tanks." It has taken all these years to admit the sequence of my 1894 patent to be correct. At one time we were told that no cleaning was necessary. I know that Mr. Greiner has withdrawn that statement, but for a certain number of years it was accepted. In the Thwaite system, non-electric, we have under suction-influences, first, the rough hydraulic cleaning and cooling of the gas; secondly, the air-cooling of the gas; thirdly, the application of centrifugal influences under combined suction- and pressure-effects; fourthly, coarse filtration under pressure; fifthly,

fine filtration under pressure; sixthly, establishment of a constant pressure. Here I might remark that the centrifugal efficiency is in proportion to the temperature—the cooler the gas as it enters the centrifugal instrument the fitter it is. Any variation from my plant is, I consider, at the cost of efficiency and economy, and has been prompted more by a desire to evade patent-rights than to secure improvement. I am glad Mr. Reinhardt supported the use of a pressure-governor holder, which has been an essential feature of my system from its practical inception. Reading between the lines of Mr. Reinhardt's peroration we are almost justified in assuming that the maintenance of German iron-trade prosperity is largely due to the application of blast-furnace gas-engines in German works. But is it not a fact that the splendid enterprise is a product of the continuous German prosperity, proved by the unbroken line of the curve of increased pig-iron output, which has risen far higher than that representing the progress of our iron trade? Although the engines described show well-appreciated progress, and the attained stage of perfection justifies the concentration of enormous powers in one unit of grouped cylinders, I hope that the workers in the field of gas-engine design will persevere in attempts to secure still further triumphs.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Deutschman's Cave, Near Banff, B. C., Canada.

BY W. S. AYRES, BANFF, ALBERTA.

(New York Meeting, April, 1907.)

I. Introduction.

This cavern was discovered Oct. 22, 1904, by Mr. Charles H. Deutschman, in company with whom I made, May 29 to June 3, 1905, at the request of Mr. Howard Douglas, Superintendent of the Canadian National Parks, the first exploration of it for the Canadian government. The results were stated in a paper, orally presented, with lantern-views from my photographs, at the British Columbia Meeting of the Institute, Victoria, B. C., July 5, 1905.* The present paper embodies also the results of a second examination, made Oct. 25 to 29, 1905.

The accompanying map, Fig. 1, will serve as a guide to the following description.

II. Location.

The cavern is situated at snow-line, at the head-waters of Cougar creek, on the west slopes of the Selkirks, about 2 miles north from Ross Peak water-tank, and 5.5 miles west from Glacier House, on the main line of the Canadian Pacific Railway. It was then reached by an arduous climb from the water-tank, up the ravine of Cougar creek, for 8,000 ft. (2,000 ft. of altitude) over rock- and snow-slides, and through a thick tangle of alders. But an easy and very picturesque trail has, during the past summer, been opened by the government from Glacier House.

Figs. 2, 3 and 4 represent views, not heretofore published, of the grand scenery of this region, so rapidly becoming the object of attraction to thousands of tourists from all parts of the world. These views, as well as those shown in Figs. 5, 6, 7, 8

* Withheld from publication, to await the later exploration here mentioned. See *Trans.*, xxxvi., liv. The illustrations accompanying this paper have been selected as typical from a much larger number of photographs taken above and under ground by the author.—R. W. R.

and 9, were taken from different points in the neighborhood of the cave, or on the way to it. Many other beautiful and sublime pictures of glaciers, twin lakes, forests and cascades could be added from the same region.

III. The Rocks and Their Formation.

The cave occurs in hard crystalline limestone, dipping about 30° to the east, and, according to the Canadian Geological Survey, belonging probably to the Devonian age. The beds are very thick, and are made up of alternate bands of white, mottled and gray marble. Some of the bands are so highly impregnated with fine grains of sharp sand that excellent whetstones can be made from them. The limestone rocks have not been completely changed into marble at all points, as will be noted under the next head, yet the change has been sufficient to obliterate all fossils.

The cave has undoubtedly been formed almost entirely by water-erosion, no part of it showing any extensive evidence of a slow dissolving of the rocks. Cougar creek, which formed it, is entirely made up of glacial- and snow-water, and during the spring and early summer is a mountain torrent. The fine grains of sharp sand loosened from the limestone rock and caught in the swift current of the small stream, that at first found its way through a shrinkage-crack or a fault in some particular bed of limestone, have undoubtedly given the water an uncommon erosive power, and enabled it to carve out a mammoth subterranean water-way in solid marble. The almost total absence of stalactites and stalagmites, such as are usually found in caves, and the presence of curiously carved marble walls, of varied fantastic shapes and somber coloring, are unusual features.

IV. Cougar Creek and the Cave.

Some distance above the cave, the creek passes for 350 ft. under a natural bridge, called by us "Gopher" bridge, and this passage is of itself a picturesque cavern. Besides the characteristic water-carved walls of white and gray marble, everywhere exposed, an additional feature is presented by the circumstance that, in many places, the change of the limestone into marble has not been complete, and the incompletely

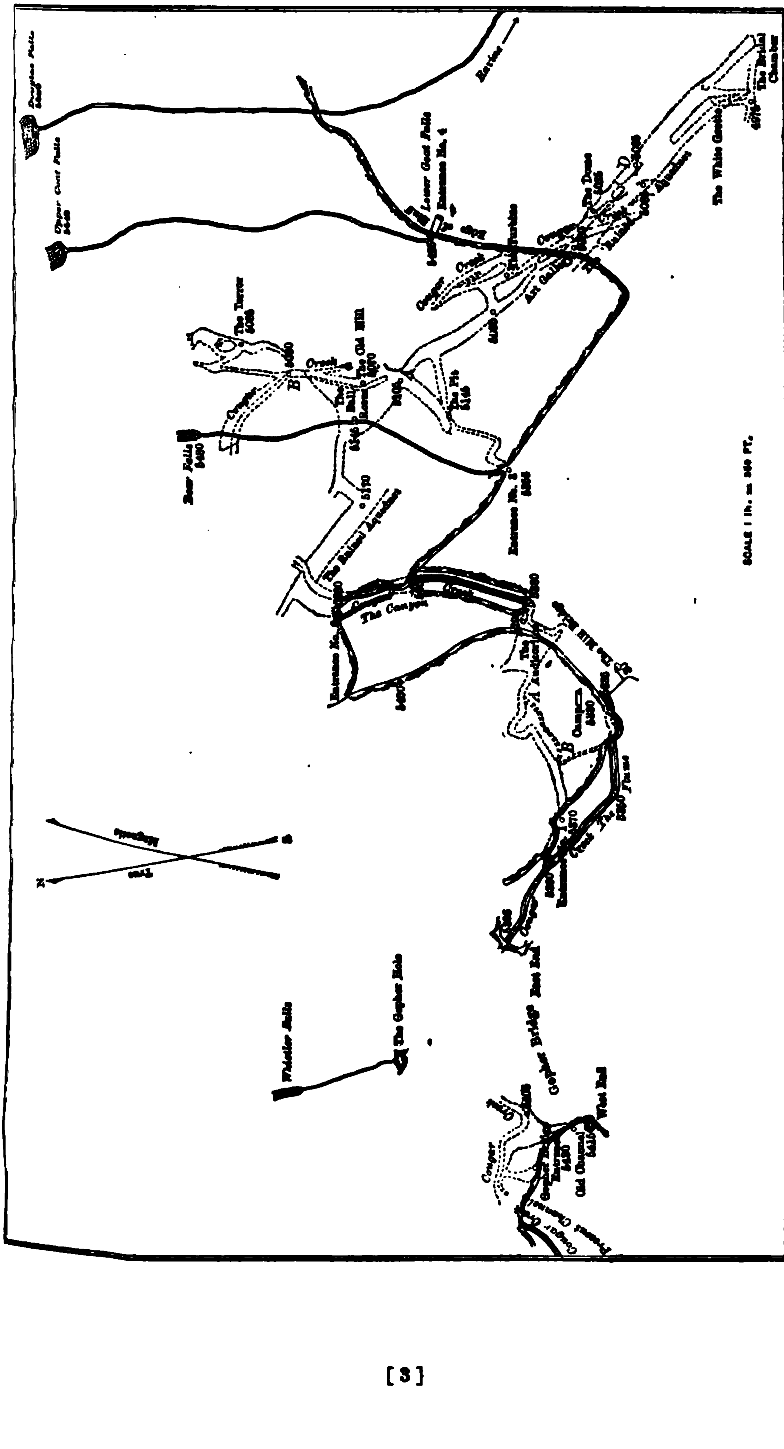

FIG. 1.—SKETCH-MAP OF DEUTSCHMAN'S CAVE, FROM A PRISMATIC COMPASS AND CLINOMETER SURVEY.

altered parts of the rock stand out in bold relief, while the marble between them has been eroded to a considerable depth. The geologist may here distinguish, much more clearly than in ordinary surface-exposures, the various stages of the metamorphosis of the original limestone into the present marble. There are evidences also of (comparatively small) cavities in the original limestone beds, formerly filled with white carbonate of lime, which was afterwards changed to marble during the metamorphosis of the limestone. Some chips and nodules of quartz, imbedded in these fillings, appear to have been carried into the cavities by water. In the gray and white marble, shrinkage-cracks are everywhere seen, which were formed during the early solidification of the limestone, and filled with carbonate of lime. They now appear as seams of white marble, usually at right-angles to the bedding of the rocks.

The creek, which now enters under Gopher bridge at the point marked "Present Channel," on Fig. 1, formerly had an entrance at "Old Channel" (now choked with drift), and also one at "Gopher Bridge Entrance," through which we descended into the cave. Westward from this point, "Grizzly" glacier, the source of Cougar creek, may be clearly seen. It derives its name from a grizzly bear which disputed Mr. Deutschman's right to invade his territory. The skin of this bear has been presented to me by Mr. Deutschman.

"Entrance No. 1" (Fig. 5) is 200 ft. down stream from Gopher bridge; and, 310 ft. below this opening, the creek plunges under a second natural bridge, 243 ft. long, called the "Mill" bridge, by reason of the roaring, as of many water-wheels, of the tumultuous stream beneath. The channel between Entrance No. 1 and the Mill bridge, which we named the "Flume," is cut in solid rock, and shows many pot-holes. For 160 ft. the descent is moderate; but for the next 150 ft. it follows the dip of the strata (30° E.), and the water plunges through a series of deep, connected pot-holes (Figs. 10 and 11).

At the east end of Mill bridge the creek emerges into the "Canyon," about 170 ft. deep and 234 ft. long, at the end of which it abruptly enters the cave by "Entrance No. 2."

Immediately east of the Canyon are three beautiful falls (Figs. 6, 7 and 8), named respectively "Douglas," "Upper

Goat" and "Bear" falls—the first in honor of Mr. Howard Douglas, Superintendent of the Canadian National Parks.

Fig. 9, taken from a point on Cougar creek about 1,000 ft. south of the cave, shows in the distance "Lower Goat" falls. At the foot of this cascade is "Entrance No. 4," through which all the water at once disappears into the cave. These falls can be seen from the railway, just west of the Loop.

Fig. 12 shows Cougar creek, in its passage beneath Gopher bridge.

Entrance No. 1 is the place where a part of the waters of Cougar creek sometimes enters the cave, particularly during very high water. Passing down this water-way, which follows the dip of the strata, the varied forms of the water-erosion are to be seen here to a better advantage than perhaps anywhere else in the cave. The walls have been fantastically carved by the torrents of snow-water that have rushed through it for centuries, and the channel is made up of a succession of rounded cistern-like cavities formed by the swirl and plunge of the water. The bottoms of these pot-holes still hold the boulders of quartzite that have ground them deeper and deeper; and the thin margins, where their walls have been worn through into adjacent holes, bear witness to the marvelous strength and hardness of the rock. The bands of white, mottled and gray marble are shown in beautiful contrast, and, when wet, appear to be polished. This passage is from 4 to 10 ft. wide by from 10 to 30 ft. deep.

Fig. 13 shows the "Auditorium," containing some stalactites of ice and other ice accumulations, with Cougar creek in the center. It has an area of about 50 by 60 ft., and is about 150 ft. below the surface. From here the creek flows into the Canyon, 20 or 30 ft. away. The Auditorium will form the best pathway into the Canyon, when some *débris* has been cleared away. At present, to enter the Canyon from the surface would require a stairway more than 100 ft. long.

During our first exploration through Entrance No. 1, Cougar creek, suddenly rising and dividing its waters at the falls near the entrance, deluged this portion of the cave. We were drenched; our lights were put out, and we were obliged to abandon this passage-way for a time.

To get into the cave through Entrance No. 2, we descended almost vertically 85 ft. to the bottom of the Canyon by means of a rope. From the Canyon, the creek enters the largest of all the underground openings thus far discovered. It naturally should be the largest because of the accumulated waters traversing it. The average height, measured on the dip of the strata, is about 125 ft., and the width, measured perpendicular to the bedding-faces, ranges from 8 to 20 ft. The width varies because of the varying conditions of the flow of the water at the time of its formation. With all the water concentrated in one passage-way and flowing through it on a steep grade it would be narrow, and widest when on a moderate grade.

From the map it will be observed that those sections of the highest old water-way from Entrance No. 2 to the present southeasterly limit of the cave are all on a line, and that this line is coincident with the strike of the strata. The omitted sections of it have been explored sufficiently to determine that they are on the same line, but they are nearly filled with *débris* and are unattractive. The fact, however, that this old water-way, which we named the "Ruined Aqueduct," was originally continuous and straight along the strike of the strata, forms a base from which to study the subsequent changes. During its early history it undoubtedly appeared much like the passage-way in Entrance No. 1, but as the channel grew deeper and wider through erosion, many masses of rock from the hanging-wall were loosened and fell into the channel-way, thus causing an obstruction, around which the water cut its way, at the same time cutting away some or all of the obstruction itself. As a result, many enlarged places are to be seen here and there.

Still others are to be seen that have been formed as pot-holes, like round shafts, down which the water poured, keeping the boulders at their bottoms ceaselessly grinding them deeper and deeper. Under this process it was only a matter of time when, particularly at the confluence of streams, great masses of overhanging rock would be unfooted and dropped into the enlarged channel and pot-holes. This is shown to a marvelous degree where the waters of Bear falls formerly joined Cougar creek through "Entrance No. 3." Portions of the old channel-way and of the very large pot-holes, notably the "Pit," which is 120

FIG. 2.—COUGAR MOUNTAIN AND ILLECILLEWAET RIVER, VIEWED NORTHWESTWARD FROM THE "LOOP" ON THE CANADIAN PACIFIC RAILWAY.

FIG. 3.—VIEW SOUTHEASTWARD FROM THE CAVE. ROSS PEAK ON THE RIGHT; THE GREAT GLACIER ON THE LEFT; AND COUGAR CREEK IN THE CENTER.

FIG. 4.—VIEW EASTWARD FROM THE "LOOP," SHOWING MOUNT SIR DONALD ON THE RIGHT.

FIG. 5.—"ENTRANCE NO. 1" TO CAVE, SHOWING MR. DEUTSCHMAN, THE DISCOVERER.

FIG. 6.—"DOUGLAS FALLS," EAST OF THE "CANYON."

FIG. 7.—"UPPER GOAT FALLS," EAST OF THE "CANYON."

Fig. 8.—"Bear Falls," East of the "Canyon."

Fig. 9.—View from Cougar Creek, 1,000 ft. South of the Cave. "Lower Goat Falls" in the Distance, at the Foot of which all the Water Disappears through "Entrance No. 4" into the Cave.

FIG. 10.—POT-HOLES IN THE "FLUME," NEAR ENTRANCE UNDER THE "MILL BRIDGE."

FIG. 11.—POT-HOLES IN THE "FLUME" AT ENTRANCE UNDER THE "MILL BRIDGE."

FIG. 12.—CHANNEL OF COUGAR CREEK UNDER "GOPHER BRIDGE."

FIG. 13.—THE "AUDITORIUM," WITH STALACTITES OF ICE, COUGAR CREEK IN THE CENTER.

FIG. 14.—SOUTHEAST END OF THE "ART GALLERY."

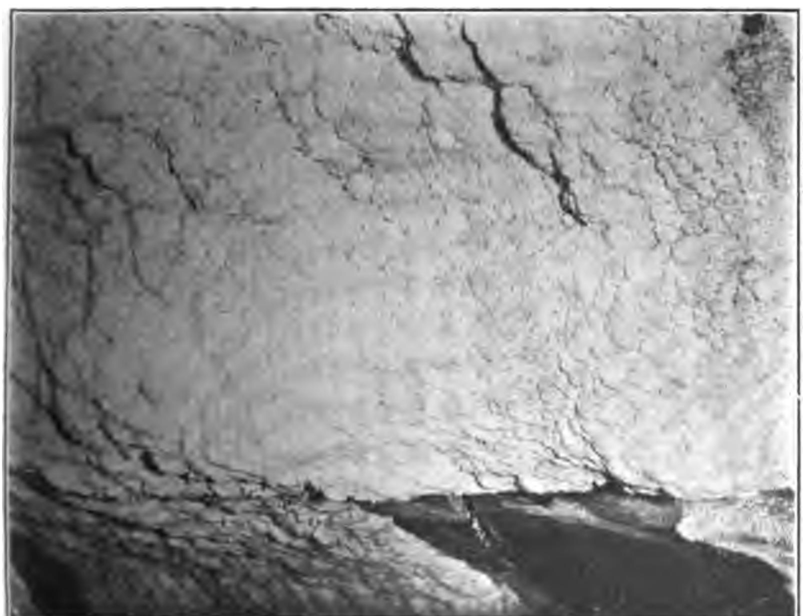

FIG. 15.—NEARER VIEW OF THE ROOF IN FIG. 14, SHOWING STRUCTURE OF LIME-ACCRETIONS.

To face p. 107.

FIG. 16.—THE "BRIDAL CHAMBER." THE BED OF COUGAR CREEK IS BELOW, AND AT PRESENT INACCESSIBLE FROM THIS POINT.

FIG. 17.—VIEW IN THE SOUTHEAST END OF THE "RUINED AQUEDUCT," OVER THE "BRIDAL CHAMBER," SHOWING A BROWN ACCUMULATION OF LIME, SURROUNDED BY PURE WHITE.

ft. deep, are here visible, the other portions being covered with fallen rocks from the roof. One of these rocks, a very large one, rests in nearly a horizontal position, and its upper surface contains about 1,200 sq. ft. of floor-space. This we named the "Ball-Room." The rocks in the Pit are of a very dark blue-gray color, and include bands of white marble, which have been crumpled by pressure to a zig-zag form.

The fallen masses of rock, wherever found throughout the cave, particularly those about the Ball-Room and the Pit, were carefully examined to determine their present stability. The roof was also examined carefully to the same end. The singular firmness of every fallen piece, even the very large ones, shows conclusively that the water had shifted all fallen pieces, great or small, into positions that are fixed and reliable. No evidence was discovered of any present movement in the roof, or of any places where the present water-erosion has made a fall of rock imminent.

At *A*, nearly opposite the Pit, we descended to the present bed of Cougar creek, at the bottom of the cave. This passage leads north directly under the Ball-Room, where the bottoms of several gigantic pot-holes, now in ruins, are to be seen. We naturally named this spot the "Old Mill." It certainly did grind for many centuries before it fell into ruin and disuse. Following up the creek to *B*, where it suddenly turns to the northwest, and continuing in a northerly direction, a series of chambers are to be found on the right of the passage-way. In the innermost of these are to be seen the most ragged walls that have been found anywhere in the cave. The jagged points and grotesque shapes at once inspire caution. This place we named the "Terror." The peculiar roughness is due to the partial metamorphosis of the rocks, and is similar to the condition found under Gopher bridge. In this case, however, the condition is accentuated by the existence of thin knife-like blades, instead of nodules, of unchanged limestone, all of which extend from 0.5 in. to 2 in. beyond the general surface of the marble holding them. The extreme south end of this inner chamber, which is 400 ft. below the surface, rises suddenly; and from its proximity to Bear falls, the inference is almost conclusive that it was at some time the inlet passage of the waters from those falls, yet it might as well have been

the inlet from Upper Goat falls. Several other passages are also to be seen entering it from the north, near the roof; but they are all inaccessible, being nearly filled with gravel. They all enter it near the roof.

Along this northerly passage, toward the chamber called the "Terror," the gravel in the bed of the channel is of a very different character from that in the bed of Cougar creek above the junction-point *B*. It is chiefly of a dark brown or reddish quartzite, while that found in the creek consists of marble and schist with occasional pieces of light or nearly white quartzite. This same dark brown quartzite had been observed at Bear falls, which corroborates the inference that the waters from these falls formerly entered the cave by this route.

This entire passage from the Terror to the Old Mill has been formed along a fault, which inclines upward at an angle of about 65° to the west. Along its line on the surface the ravine of Bear falls has been formed, and also the depression through which its waters now flow to Entrance No. 3. From this entrance these waters have cut their way down into the cave along the same fault, joining Cougar creek at the Old Mill, and in their passage have formed the Pit. This portion of the cave, just described as formed along the fault, is one of the most interesting and instructive sections thus far explored. It tells a long history from the first grinding at the Old Mill to the erosion of the present day.

Returning again to the point *A* and continuing along the passage-way, which from here runs in a southeasterly direction along the strike of the strata, many interesting features are met. The opening consists of a series of levels through which the water has successively carved its way, beginning with the Ruined Aqueduct, already described, and ending with the present bed of Cougar creek, 125 ft. below it. Among the most attractive spots are the "Turbine," the "Art Gallery," the "Bridal Chamber," the "Dome" and the "White Grotto."

At the Turbine, Cougar creek makes a reversed bend in the form of an overturned letter S. Immediately in the curve occurs a series of steep inclines and falls with a vertical drop of about 25 ft. Around this reversed bend and down these inclines and falls, the water, in the flush season, rushes and swirls

with a deafening roar, which is greatly intensified by its reverberations in the cave.

Below the falls the course of Cougar creek is diagonally to the right across the strata, and its level is about 60 ft. below the passage-way. Just at the side of the present bed of Cougar creek, beginning just below the falls, is an old channel formed along the strike of the strata, from which are to be seen, looking up, two very large pot-holes, 18 ft. in diameter, and in a perfect state of preservation. One of them, with an arched roof about 40 ft. from the bottom, is decorated with carbonate of lime accumulations so delicate and dainty in effect that it might be the enchanted chamber of the fairies. This pot-hole we named the "Dome." All progress down along the course of Cougar creek from this point was barred by a very low roof at the side and by the steep descent and swift current of the creek itself.

Returning to the passage-way by which we were advancing, and proceeding southeasterly, we passed through an old water-course beautifully decorated with lime-accumulations, which we named the "Art Gallery." Fig. 14 shows the southeast end of it. Fig. 15 is a nearby view of a small section of the roof shown in Fig. 14. This lime-accumulation is white or creamy white, with an occasional tint of pink. It resembles heads of cauliflower set close together without any intervening spaces.

From the Art Gallery our course was down over large masses of fallen rock for a distance of several hundred feet to a narrow passage, continuing for another hundred feet, at the end of which we entered a beautiful room, which we called the "Bridal Chamber" (Fig. 16). The decorations of carbonate of lime are creamy white and are very dainty. This room is formed against a fault, and Cougar creek is here deflected by it to an easterly course. No way of getting down to the present bed of Cougar creek at this point, without ladders, was discovered. The roar of water plunging down a steep incline could be clearly heard, and it is assumed that the creek continues along this fault for some distance. We were greatly disappointed in not being able to descend to its bed, as this seems to be the only avenue of entrance to the openings that unquestionably exist between the Bridal Chamber and the

place where Cougar creek emerges to the surface. Just where this last point is we have not been able to determine, as no outflow of water sufficient to locate it positively has thus far been found on the surface.

Immediately over, and about 125 ft. above the Bridal Chamber, is the extreme southeasterly end of the Ruined Aqueduct. Fig. 17, from a photograph taken in that section of it which lies above the Bridal Chamber, shows a beautiful brown accumulation of lime surrounded by a drapery of pure white.

A small cave exists directly over Entrance No. 2, at the north end of the Canyon, which has been explored and named the "Ice Cave," because a part of the winter's accumulation of ice remains in it during the entire summer.

The Canyon and the Ice Cave have been formed along a fault, nearly or quite parallel to the fault previously described as extending from the Terror to the Old Mill. The parallelism of these two faults and of the beds of the streams leading from Upper Goat and Douglas falls, gives a hint at the possibilities of finding very extensive openings along the faults that probably formed the beds of these streams, similar to the openings found along the fault that formed the ravine of Bear falls.

As already remarked, the waters from Lower Goat falls immediately disappear into the cave at the foot of the falls. They then flow underground northerly for a few hundred feet, and then descend nearly vertically into unknown cavities below. Just where the stream from these falls joins Cougar creek has not been determined, but it is quite probable that the junction is beyond the Bridal Chamber in a southeasterly direction, since no branch passage has been discovered, between the Old Mill and the Bridal Chamber, corresponding in size with the entrance at the foot of the falls.

1. *The Extent of the Cave.*

The total length of the passage-ways I have surveyed and measured thus far amounts to about 4,000 ft. What lies beyond the Bridal Chamber, between it and the place where Cougar creek comes to the surface, and also what exists along the faults which have formed the beds of the streams from Douglas and Upper Goat falls, is entirely unknown; but great

possibilities are suggested as to the existence of caverns even larger and more beautiful than any thus far explored. One suggestion seems almost certain—namely, that beyond the Bridal Chamber the openings must be at least as great as those between this point and Entrance No. 2. In fact, this should be the largest part of the cave, by reason of its being a continuation of the portion already explored, with added waters to aid Cougar creek in forming it.

2. *The Probable Age of the Cave.*

Notwithstanding the fact that the rocks belong to a comparatively old series, the beginning of the cave undoubtedly dates from recent geological time. Any attempt to estimate its age by assuming a rate of erosion would be mere guesswork. Actual rates of erosion for one locality or one kind of rock would not apply to this particular case, even though such data were at hand. Therefore, no intelligent estimate can be made until the present rate of erosion has been determined. In my report to Mr. Douglas for the Canadian government, I have suggested the value of such a determination, and have pointed out that "in several places along Cougar creek, in the bottom of the cave, an excellent opportunity is afforded to determine accurately the present annual rate of erosion. A micrometer measuring-apparatus should be used, and accurate computations made of the area of the cross-section of the rock eroded per year; also of the quantity of water passing a given section in one year, and its velocity. From these data the ratio between the area of the cross-section of the average stream and the area of the cross-section of the rock eroded could be determined. In other words, the volume and velocity of water required to remove the rock eroded in a year could be found." The nature and quantity of the materials carried by the water should be determined and measured at the same time and with the same degree of accuracy, for the reason that the sand, gravel and other materials thus carried form the eroding instruments of the water, and are made effective by its velocity and momentum. These cross-section measurements should be made at a sufficient number of places to determine the rate of erosion under different velocities of the current, for it must be borne in mind that where the sand and gravel lodge in the bed

of the stream, the rate of erosion is many times smaller than where the bed is continually swept clean by a more rapid current.

On the assumption of $\frac{1}{32}$ in. a year, it would have required 48,000 years to erode the 125 ft. of depth of opening found in the cave.

3. *Has the Cave Ever Been Inhabited?*

No evidence whatever was discovered that any portion of the cave has ever been inhabited by human beings or wild animals. The continued rapid circulation of air through the cave causes ice to form in great quantities in some parts during the winter, and lowers the temperature throughout the cave to such a degree that it would not be an attractive home for man or beast. In addition to the low temperature in winter, the thunder and roar of the cataracts in the cave during the spring and summer, particularly while the high water exists, would make it a highly disagreeable habitation.

Postscript.—Since this paper was presented, the Canadian government has constructed a good trail to the Cave, where it has built three cabins, one as a residence for Mr. Deutschman, who is to be the care-taker, and the other two as shelters for visitors—men and women respectively, The excursion to the Cave can therefore now be made without danger or hardship by tourists of all classes; and, since the Canadian Pacific Railway Co. intends to advertise it widely as one of the attractions of the National Park, it will soon become known to thousands who now hear of it for the first time.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Comparison of American and Foreign Rail-Specifications, with a Proposed Standard Specification to Cover American Rails Rolled for Export.*

A Discussion of the paper of Mr. Albert Ladd Colby, presented at the London Meeting, July, 1906.

MR. E. WINDSOR RICHARDS, London, England:—In reading this paper the most interesting point to me was the question of the maximum percentage of phosphorus allowable in the steel rail. Mr. Colby said, and we will all agree with him, that the engineer knew, and even a steel-rail maker grants that phosphorus is the most undesirable constituent of steel. We in England have been for a long time considering a specification for the supply of steel rails. This matter has been taken up by the Institution of Civil Engineers, the Mechanical Engineers, the Iron and Steel Institute, the Institute of Naval Architects, and the Electrical Engineers. Committees have been formed, and the whole matter has received most careful attention. They arrived at last at an analysis which I will read: "The carbon is to be from 0.35 to 0.5 per cent.; the manganese from 0.7 to 1.0 per cent.; the silicon, not to exceed 0.10 per cent.; phosphorus, 0.07; and sulphur, 0.07 per cent." As to the phosphorus, which is the most important point of all in the analysis, we have for many years, and indeed until very lately, always agreed to supply steel which would not contain above 0.06 per cent. of phosphorus. Iron-ores are not quite as good now as they were formerly, and the manufacturers at the meetings of the committees referred to, tried to obtain an increase in the allowance of phosphorus. They asked the Sub-Committee to agree to 0.08 per cent. of phosphorus. They tried all they possibly could to obtain that; but they failed. English engineers in Great George Street and all over England, representing the important Associations I have mentioned, would only agree to 0.07 per cent. and that is the maximum allowance of phosphorus. Mr. Colby is an able advocate, but with all his ability he would not have been

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able to persuade the English engineers to agree to 0.08 per cent. Mr. Colby very ably advocates that the Americans at any rate can agree to 0.10 or 0.11 per cent. of phosphorus. English engineers consider that that is a percentage much too high, and will not agree to it on any terms whatever. And so I think that we will have to be content with 0.07 per cent. on this side of the water. Mr. Colby tells us that it is impossible for American railmakers to produce rails under 0.10 per cent. Such rails would not be received in Great Britain. I do not think in the other points of the analysis there is very much difference between us. Mr. Colby gave the chemical composition (*Bi-Monthly Bulletin*, No. 11, September, 1906, pp. 665), which, with the exception of phosphorus, I think our Standards Committee would agree to; but I think the question as to the amount of phosphorus allowable in a steel rail is the most important of all and perhaps the one which will be discussed more to-day than any other.

MR. THOMAS PRICE-WILLIAMS, London, England:—Mr. Colby kindly sent me a copy of this interesting and valuable paper, which I should much like to see in the hands of some of the chief railway engineers in this country. I observe from the comparisons made in it of the American and foreign steel rail specifications, that the physical tests vary a great deal, and among them the most notable, and in my opinion the most objectionable, are some of the "drop-tests," which are extravagantly disproportionate to the force of impact a steel rail is ever subjected to on a railway, and the requirement of such needlessly severe tests necessarily involves a considerable reduction in the percentages of phosphorus and carbon, in order to secure the material from any risk of fracture from brittleness. With regard to the chemical tests, a long list of the results of which is given in the paper, a close agreement is observable in the percentages of the requisite constituents of the material for the manufacture of steel rails of the best quality, so far, at least, as regards strength, elasticity, and freedom from brittleness and risk of fracture. No reference, however, is made in this or indeed in any other paper on the subject I have seen of late years, to another important quality in a steel rail which, from the railway company's point of view, has of late years de-

served a great deal more attention than it has received—viz., its durability and capability of withstanding the destructive effects of the enormous development of railway traffic, more especially in the increased weight and speed of the trains, which has occurred during the 40 years which have elapsed since the first Bessemer steel rails were laid down in "the running roads" of British railways. It was in fact the much more durable quality of the material which, in spite of its then much higher price, so quickly led to its general adoption as the best and most durable material for the permanent-way of railways.

In this connection I should mention that in the early days of Bessemer steel manufacture in which I was engaged, I gave a great deal of attention to the question of the durability of the material, and in the paper I read at the Institution of Civil Engineers I gave particulars of the actual amount of wear of the rail-heads of a number of steel rails laid down on portions of the Great Northern Railway, where they had been subjected to the destructive effects of the keenest traffic during a period of about eight years, the live and dead weight tonnage of which had been carefully ascertained by the then chief engineer, Mr. R. Johnson, M.I.C.E. A chemical analysis was also made of the constituents of some of the rails which showed the least and the maximum amount of wear, and portions of those rails were subsequently subjected to physical tests at Kirkaldys. The results given in the paper show that the rails which have suffered the least amount of wear of the rail-head are those containing a larger percentage of phosphorus than is now generally adopted as a maximum in British specifications, which, as Mr. Windsor Richards has just stated, is 0.07 per cent.; and coming as this does from him, with the weight of his great experience and authority as a manufacturer of steel rails, that percentage must be accepted as about the maximum which in this country is considered essential to insure the steel rail from any risk of fracture due to the brittleness of the material.

The maximum percentage of phosphorus, however, as given in the long tabulated list of American specifications, is considerably larger than is considered justifiable in the specifications in this country, and in many cases a maximum of 0.10 per cent. is specified. It is remarkable that the Great Northern

rail which in a period of nearly eight years showed the least amount of 0.12 in. of wear of the top table, after having been subject to a traffic of 59¾ million tons, contained just that amount of 0.10 per cent. of phosphorus. It is also well worthy of note that it was a distinguished American engineer, Mr. Chanute, an honorary member of the Institution of Civil Engineers, who first drew attention to the greater endurance of the Great Northern steel rails alluded to which contained the higher percentages of phosphorus, which led to his adoption of the phosphor unit as a standard.

The maximum percentage of phosphorus observable in the American specifications is 0.10 per cent., as already stated, and the minimum 0.07, the exact maximum percentage adopted in this country. It would be interesting to know the amount of wear of the rail-heads or top tables, and of the traffic tonnage which had produced it, in the case of some of the American rails containing the maximum and the minimum percentages of phosphorus. The results, however, obtained from the Great Northern rail-tests sufficiently show that although, when devoid of any phosphorus, a steel rail is rendered less liable to the risk of fracture from an excess of it, the presence of some moderate percentage, as yet indefinite, certainly has the effect, as Mr. Chanute has pointed out, of very largely increasing the durable quality of the material.

To insure immunity from any risk of fracture is obviously the primary object of all steel-rail specifications. With the long and valuable experience we now have, its serviceable life as measured by time is now quite an easy matter. What is most needed now is the means, equally available, as in the case of the Great Northern rails, of ascertaining the serviceable life of these American rails as measured by the actual amount of wear of the rail-heads of those containing the maximum and the minimum percentages of phosphorus, together with the amount of the traffic tonnage which caused it.

There can be no question that the wear of steel rails subjected to the destructive effects of the great increase in the weight and speed of the main-line traffic of the principal railways in this country is far greater than is generally supposed, as is testified in fact by the results of the tests of the Great Northern rails, already alluded to, where in some cases as much as

0.5 in. of the rail-heads was worn away in the short space of about eight years (practically the serviceable life of the rail as measured by the traffic tonnage and amount of wear of the rail-head), while other rails almost adjoining them, and subject to the like amount of traffic tonnage, and possessing all the other requisite qualities to insure safety from fracture of the material, experienced only one-fourth the amount of wear. Under these circumstances it is a matter of great importance from the railway company's point of view that only steel rails possessing the highest qualities of durability consistent with those for insuring security from risk of the fracture of the rail, should be used, and thus maximum serviceable life obtained.

There is everything to indicate that with some slight modification of the percentages of the constituents of the material, a rail of at least as high or even a higher quality of durability than that attained in the case of the Great Northern may soon be regarded as an essential requirement in all steel-rail specifications.

The annual cost of the maintenance and renewal of the permanent-way of the principal railway systems in Great Britain constitutes a large item of the working expenditure; and taking the London & North-Western Railway, the premier railway, by way of illustration, it amounted in 1904 to considerably more than half a million, or just one-seventh of the entire working expenditure. It is scarcely necessary to say, that anything like an approach to an increased durability of steel-rail material, such as mentioned in the case of the Great Northern rails, would largely contribute to the reduction of the working expenditure of that and most of the other great railway systems, which has now reached the exceptionally high figure of from 63 to 64 per cent. of their gross traffic receipts.

Mr. F. W. Harbord, London, England:—As to this question of phosphorus, we all agree that a specification should be drawn so that manufacturers can conform to it, and, if the position in respect to ores in America is such that 0.1 per cent. of phosphorus is the minimum that they can give in their rail-steel, it is only reasonable that this limitation should be made. In England I think we may say that the manufacturers are in a rather happier position, inasmuch as they can work regularly

and systematically without any great trouble to a specification of 0.08 per cent. of phosphorus, and if they can do this, there is no reason why the limit should be raised to 0.10 per cent. I think 0.08 per cent. is a more reasonable limit than 0.07 per cent., but still the powers that be, have settled upon 0.07 per cent. and I think we can, by taking great care, work to that. I take it that this 0.10 per cent. phosphorus limit refers to the Bessemer process, but now that the basic open-hearth process is coming largely into use in America, there should be no difficulty in making rails 0.08 per cent., or less if required. The question of manufacture has an important bearing upon the carbon, and I think that it is a great pity that the content of carbon in reference to manufacture has not been dealt with in specifications. My experience is that with a given content of carbon we get a different degree of hardness, depending largely upon the method of manufacture—that is to say, a basic open-hearth rail of 0.50 per cent. of carbon is distinctly softer than a steel rail made by the acid process. So that for the basic open-hearth rail we can take a higher carbon with lower phosphorus, and still be within the region of safety. I have had lately some rails brought under my notice which gave most excellent drop-test results, containing from 0.6 to 0.7 per cent. carbon, made by the basic open-hearth process. This question of the influence of manufacture will have to be considered, as otherwise if we have the same carbon-content for basic open-hearth as we have been accustomed to specify for acid steel, we will get the rail-heads spreading, and other troubles. We must not, therefore, draw hard-and-fast lines by saying that we will not have rails of a certain percentage of carbon without taking into consideration the method of manufacture.

Mr. R. A. Hadfield, London, England:—I wish to compliment Mr. Colby for the information he has given to us. We wanted to know what our American friends were doing; but I think if Mr. Colby had made his propositions to the Standards Specifications Committee he would have found a large number of English engineers against him, and he would have found difficulty in persuading them that steel containing 0.10 per cent. of phosphorus was a safe material to be used. Mr. Colby gives us a table of American rails not having been broken, although

they contained 0.10 per cent. of phosphorus. I would like to ask Mr. Colby as to the remaining constituents present. It is quite possible to have 0.10 per cent. of phosphorus, provided that the carbon is not too high, and the manganese is sufficiently high. M. Euverte, many years ago, read a paper in reference to the combined influence of manganese and phosphorus upon steel, in which he showed that phosphorus was not so deleterious as was thought; at any rate, that was his opinion. Mr. Colby stated that if the carbon was low we might push up the percentage of phosphorus probably to the limit which was mentioned; but, as he also pointed out, in American conditions, the higher the carbon, within certain limits, naturally the greater durability of the rail. I do not know whether Mr. Colby was present at the National Physical Laboratory on Tuesday, where we had the alternating-stress machinery at work. I would suggest to him that if he could send some specimens containing as much phosphorus as he spoke of, and let Dr. Glazebrook carry out the tests upon steel containing high phosphorus, he would then find out whether it is a safe material when the carbon is at the same time high. The paper is an excellent one. It has elucidated points which have been under consideration for the last few years, and we are very much indebted to Mr. Colby for it.

Mr. J. E. Stead, Middlesbrough, England:—I have only one or two remarks to make in reference to the standard of phosphorus in rails. I think chemists and metallurgists in this country are all agreed that if they raise the carbon, the effect of phosphorus becomes more and more pronounced. I cannot go into the reasons for it on this occasion, but they are pretty well known scientifically. If we raise the carbon we must lower the phosphorus. With reference to the standards instituting 0.10 per cent. of phosphorus, I think it would be a mistake to make it so high in this country and for the United States of America, for the reason that if we allow 0.10 per cent. in a contract, manufacturers naturally will say there should be a swing of the pendulum with 0.10 per cent. as about the average, and they should be allowed one or two points above 0.10 per cent. For this reason it is proper and correct to place the basis low, so that the average is not more than 0.07 or 0.08 per cent.

But I think we would be very ill-advised to reject rails if the limit exceeded in one particular rail, or a few rails, 0.07 or 0.08 per cent. provided the other elements are not very high or in objectionable proportion; then 0.10 per cent. even might be allowed without rejection. I find that as regards broken rails, high manganese causes more fractures than phosphorus. High manganese and high carbon together are very treacherous, and while high manganese makes the rails brittle if they were rolled and cooled on a cold winter's day, yet, if rolled in the summer, and the rate of cooling retarded, they would most probably be all right, and wear better than rails of normal composition. Manganese should not exceed 1 per cent. in rails. I think that metallurgists do not pay sufficient attention to the effect of manganese in rails, and sometimes the brittleness is put down to the phosphorus instead of to the high manganese.

Mr. James E. York, New York, N. Y.:—As a boy I was associated with the rolling of double-headed rails. I think the bull-headed rail had not been introduced at that time. The physical treatment of rails has a great deal to do with their durability. Mr. Stead has said that on a cold day high manganese is rather destructive to the tenacity of the rail. Mr. Stead might also have said that a low finishing temperature in rolling the rail is also detrimental to its physical qualities from the fact that the section of the rail does not permit of a uniform flow of metal at the same surface speed per minute throughout the section. That condition is apt to leave an internal stress in the rails, which may thus yield to a sudden blow in the track. That applies in a much greater degree to the rolling of a T or Vignoles rail, as used in America and elsewhere, than it does to a double-headed or bull-headed rail as used in England, from the fact that in the double-headed or bull-headed rail both the base and the head are generally of the same width, thus permitting a more uniform flow of metal in the rolling. That, in my opinion, accounts for the less frequent fractures in the double-headed or bull-headed rail than in the T-rail. I wish to ask why it is that rails in Great Britain do not break to such a degree as the T-rails of the United States of America? In my opinion it is entirely owing to the difference in the shape of the two rails. If the rails are rolled

at a low temperature, so as get the best physical results through securing the fining of the grain, the result is an unnatural stress left to a greater extent in a T-rail than in a double-headed rail, because of the difference of the uniform flow of metal during rolling. To illustrate that, I would point out that the diameter of the roll to form the web of a T-rail is in some instances at least 5.5 in. larger than the part of a roll which forms the extreme width of the flange. The result is that the small diameter only gives off the metal at a much slower rate than the part forming the web, consequently the wider part of the section will either slip or stretch during the operation, and the result is that internal stresses are left inherent in the finished section. That occurs much more with the T-rail than it does with the double-headed rail referred to, which lends itself to a more uniform flow of metal than the T-rail, during rolling. An illustration of that can be seen by the much larger amount of crop-ends from a T-rail when rolled, than from a double-headed or bull-headed rail, the conditions as to ingot or billet being the same. Mr. Hunt some time ago in one of his papers stated that some of the rails made in Great Britain in the early sixties had proved conclusively that the heat and physical treatment were much more important than the chemical constituents. They were in the track in active service 35 to 40 years, and their durability had been so satisfactory that it was decided to have them analyzed, and they were then found to contain three times as much phosphorus as is now thought judicious, and also other impurities. In spite of that they had not broken, and answered the purpose for which they were produced. Now railroad engineers are complaining of the poor quality of the rails produced by modern practice. Railroad engineers have asked me what the cause of the difference in quality between the rails made in the past and in the present is, but, as I am not interested in the manufacture of rails, I said very little about it. In my opinion, however, the good quality of the older rails has been largely due to the mechanical treatment of the metal at the time of rolling.

Mr. A. Lamberton, Sheffield, England:—I wish to refer to a point not touched on by the previous speakers. A good deal has been said as to the percentage of phosphorus permis-

sible in rails, and Mr. Colby has referred to phosphorus as high as 0.11 per cent. in some American rails, which had given good results, but that would be regarded as quite unsafe in this country. I think the probable explanation is to be found in the difference in construction between American railroads and those in this country. In America the rails are invariably of flat-bottom section, resting directly on wood ties placed at closer centers than in British practice. This form of construction is beneficial in that it tends to modify the intensity of the shock and vibration imparted to the rail. I think that a rail with a tendency to brittleness would be likely to stand better under the conditions due to this form of construction than if it formed part of a British railroad, where the rails rest on hard cast-iron chairs and the shock and vibration are more severe. Certainly rails having 0.11 per cent. of phosphorus would never be accepted in Britain, and I think it too high, no matter what form is adopted. At the same time, I believe it might be less objectionable in the American system of construction than in the British.

MR. ROBERT W. HUNT, Chicago, Ill.:—I am convinced that the process of manufacture in America will be forced to change owing to ore conditions, and I believe that in a very few years the question of limitation of phosphorus will lose its significance in the country. At the present time, however, it exists. There is a great deal of difference of opinion about it. A great organization, the Engineering and Maintenance of Way Association, composed practically of all the representatives of the railroads of the country, has adopted a specification in which they limit the phosphorus to less than is proposed in the paper. It is not fair, however, to say that the American Society of Civil Engineers have committed themselves to that position, because as the report of their Special Committee on Rails has not yet been accepted by that Society, its position cannot be assumed.

MR. E. F. KENNEY,* Philadelphia, Pa. (communication to the Secretary)†:—The author has certainly been misinformed re-

* Engineer of Tests of the Pennsylvania Railroad Company.

† Received July 13, 1906.

garding the rail situation on American railroads. Very convincing testimony has been furnished to both the American Society of Civil Engineers and the American Railway Engineering and Maintenance of Way Association, showing that nearly every American railroad having heavy traffic is suffering greatly from broken rails. The rails are not giving satisfaction as to wear; and any attempt to improve the wear by making the rails harder is met by a crop of brittle rails. This brittleness is caused by high phosphorus. Rails with lower phosphorus have been made, in which carbon was quite high, thereby getting much better wearing-qualities without being brittle; but as long as the phosphorus is kept up around 0.1 per cent. it will be impossible to get rails which will wear well without being dangerous. Far from being what the author seems to think it, the brittle rail is one of the most important subjects before American railroads to-day. Phosphorus is an unmixed evil; and any reduction in phosphorus-content will mean much to the users of the rail, both as to wear and safety. If the softness asked for in the foreign rails is required for safety, raising the phosphorus-content will necessitate lowering the carbon, to get equal insurance against brittleness. The arguments in favor of raising the allowable phosphorus-content are not sound. Careful heating and lower finishing-temperature might overcome a difference of 0.02 in phosphorus if the lower-phosphorus rail had been heated too high and finished too hot; but there is no reason why the low-phosphorus should not be as well heated and finished as the high-phosphorus material.

Moreover, there is small likelihood of getting rails well-heated and finished under the proposed specifications. They contain no limitation whatever of the finishing-temperature, so that cold-finishing is not likely to be obtained. The recent American specifications all fix a maximum shrinkage allowance to regulate this, but it is steadily opposed by the manufacturers.

The proposed specifications make no mention of hot-straightening. This is most unfortunate, since many of the broken rails reported by American roads can be traced directly to injuries received in straightening. The hot-straightening is often carelessly done. The rails come down to the straighteners in very bad shape, which necessitates a great deal of severe gagging in the straightening-presses. This evil has attained

such proportions that I have proposed the specification of of a maximum camber for rails arriving at the straightening-presses, and the requirement that all rails having a greater camber, or having sharp kinks, be marked as No. 2 in quality before being straightened, and only accepted as such. This requirement has been accepted by the American Society of Civil Engineers Committee on Rails, and incorporated in their specifications. It has also been adopted by the American Railway Engineering and Maintenance of Way Association, and put in their specifications. A little more attention paid to hot-straightening will reduce greatly the number of rails ruined in the gag-presses.

The word "sufficient" in Clause (*e*), relating to the cropping, should be qualified to make it more definite. It has been used in most American specifications until recently, and has been uniformly interpreted by the makers to mean "sufficient from their point of view." The inspector at the mill has no voice in the matter. All that is now done in shearing is to cut away the material until no black spots are shown when the bloom is cut through. There is no attempt to remove the zone of greatest segregation and unsoundness. This is not sufficient to insure sound material, and makers know it; yet they oppose the specification of a definite discard. A certain percentage of the whole ingot should be specified as the minimum discard from the top.

Mr. W. E. FREIR, London, England (communication to the Secretary)* :—The presentation of Mr. Colby's paper affords an opportunity for bringing forward a matter which is of very great importance, and which is causing much anxiety in almost every town of the United Kingdom and the Continent of Europe, as well as in many American cities. I refer to what is termed the "corrugation" of tramway-rails. In the French-speaking countries these corrugations are styled "*les ondulatoires,*" and the Germans refer to "wave-like wear." By whatever name they are known, however, these corrugations represent not merely a nuisance to the tramway engineer or manager, but also a source of monetary loss, which is of the greatest moment to the corporations and companies owing or working the tram-

* Received July 14, 1906.

ways. The cause of these corrugations is at present shrouded in mystery, and although any number of theories have been put forward, not one of them seems to be able to withstand serious practical tests. The subject was first brought to notice in *The Light Railway and Tramway Journal* in December, 1903, and January and February, 1904, when various theories were propounded as to the cause, including contributions by Mr. J. E. Stead, and several American engineers. In 1904 the question was discussed in Germany by Von Borries, Scheibe, Schwarbach, and others, and it was also found that under the guise of "roaring" rails, the defect was quite rampant on many of the lines of railway in India. More recently the subject has again been taken up very fully by *The Light Railway and Tramway Journal*, and there can be no question that it deserves the attention of rail manufacturers generally, seeing that, to the tramways of the world, it involves the possible expenditure of many millions of money for the replacement of faulty rails, and that without any guarantee that the mischief may not recur on the new rails.

The theories which have been put forward, as to the cause of these corrugations, are so numerous that they cannot very well be enumerated, but that which is of most interest to metallurgists, and particularly to rail manufacturers, is that which attributes the trouble to faults in manufacture, arising either through segregation in the ingots, improper rolling, or an incorrect finishing-temperature when rolling. Certain contributions read before this Institute, and other technical bodies, lend some color to the idea that the fault may be originated during the process of manufacture, but, on the other hand, there are many facts which lead to the conclusion that the corrugations are in no sense due to the composition of the steel or its manipulation. Then there are those who attribute the mischief to the insufficiency of the carbon, or to too-great percentages of manganese. The average weight of tramway-rails (girder section) in this country is 90 to 100 lb., and the general specification calls for carbon, 0.35 to 0.5; manganese, 0.7 to 1.0; silicon, not over 0.10 (generally 0.07 or 0.08); phosphorus, not over 0.07; and sulphur, 0.07 per cent. This, it will be seen, gives a fairly soft rail—softer at all events than the street-railway rails (T-section) mostly used in the United States; but there

would not seem to be anything in the analysis which should lead to the trouble under discussion. Nor is it easy to attribute the fault to the method of laying the rails. The theory that the use of the rails as the return half of the electrical circuit causes the corrugations, is disposed of by the fact that corrugations exist equally on cable- and steam-tramways, where no current is used. In the same way the hypothesis that, as almost all tramway-rails are made of Bessemer basic steel, therefore the process is responsible, is also dismissed by the existence of the faults on rails made of Bessemer acid steel. Tramway girder-rails in the United Kingdom are laid on a bed of concrete, and anchored down in the most rigid manner possible, fished and bonded at the joints, with no allowance whatever for expansion—contrary to the suspended flexible joints of railway practice. Yet the "roaring" rails appear in India, on the ordinary railways, and corrugations show in all sorts of places, on up-grades and on down-grades, on straight line and on curves, and on electric railways with bullheaded rails, but only, in this instance, where check-rails are used. The literature of the subject is rather meager, being practically confined, in this country, to *The Light Railway and Tramway Journal*, and in Germany to *Glaser's Annalen* of 1904, yet there can be no question of the high importance of the matter, and that it is one which merits the attention of the Iron and Steel Institute and of the American Institute of Mining Engineers. Tramway engineers are endeavoring to remedy the corrugations by grinding the head of the rail with emery or other grinders, but this is obviously a mere make-shift arrangement, and they would welcome any suggestions which would prevent the occurrence and recurrence of the fault. Is it possible that a harder rail would be less liable to develop these corrugations? Do American rails of 90 to 100 lb., with 0.50 to 0.60 per cent. of carbon, and 0.80 to 1.10 per cent. of manganese, and phosphorus up to 0.10 per cent., wear free from these wave-like depressions? Is there anything in the idea that the rigidity of the tramway-track is conducive to the production of the mischief?

These are questions which are of moment, and if the discussion on this paper should furnish answers to them, I am sure the tramway-men of the world would be very grateful for the information.

Mr. William R. Webster, Philadelphia, Pa. (communication to the Secretary)*:—In this country rails for export-orders have been and are now being manufactured and tested in strict accordance with all of the requirements of some of the most severe specifications referred to by Mr. Colby. It is only after an engineer has been convinced that rails can be made here equal in every respect to those he is getting abroad, that he should be asked to modify any conditions in his specifications, and then only to accept such requirements as have the indorsement of our railway companies and engineers.

The standardization of rail-specifications in this country is in very good hands: the American Society of Civil Engineers, the American Railway Engineering and Maintenance of Way Association and the American Society for Testing Materials have each appointed special committees to do this work. Some of the members of these committees serve on two committees and some on all three. Much of the work has been done independently, but the findings of each committee have been considered by the others, and joint meetings have been held. But notwithstanding all this, there are still differences in their specifications on the following points, which are now under consideration by all the Societies and committees:

Chemical Composition.—One of the committees calls for lower phosphorus and higher carbon than are usually specified. The second agrees with this, except that they have a note stating that the carbon can be modified to suit local conditions. The third calls for higher phosphorus and lower carbon than the first, claiming that equivalent results can be obtained in the rails if they are rolled properly.

Drop Test.—All of the committees agree that the butt end of rail taken for test shall be from the top of the ingot. Two of them agree on the height of drop for each weight of rail, and require a test from each heat of steel; the other committee considers one test from every fifth heat of steel, and a less height of drop, sufficient, on account of rail being taken from the top of ingot.

Discard.—Only one of the committees considers the usual clause—"sufficient discard from the bloom shall be made to insure sound rails"—is satisfactory. The second asks for more

* Received July 13, 1906.

than the usual amount and specifies the length from bloom to be discarded. The third does not consider this satisfactory and specifies a given percentage of the weight of ingot to be discarded, in order to cover the use of different weights of ingots.

Temperature of Rolling—Shrinkage Clause.—All of the committees appreciate the importance of putting enough work on the steel at a low temperature to break up the coarse structure. They agree that the temperature of the rail at the time of leaving the finishing-pass is a fair indication of how this work has been done, the other conditions of rolling being known. Also, that the amount a rail of given length contracts or shrinks after being cut at the hot saws, in cooling to normal temperature, is the most convenient check on the finishing-temperature. As the distance of the hot saws from the rolls varies at the different mills, the time between the rail leaving the finishing-pass and its being sawn, also varies: a correction has to be made for this time, and has been agreed on by all three committees. They also agree on the differences in shrinkage called for between the heavier and the lighter rails. Two of them agree on the amount of shrinkage to specify at the time of the rail leaving the finishing-pass and the other asks for a larger amount, or higher finishing-temperature.

As a member of the committee of the American Society of Civil Engineers, and as Chairman of the other two committees, I desire to state that an earnest effort is being made to harmonize these differences, and to secure rails best suited to withstand the severe conditions imposed by increase of wheel-loads and speed of trains.

It is expected that standard specifications will be agreed on that will be satisfactory to all.

The Standards Committee of England has, through its Secretary, been kept advised of what is being done in this country: and the Secretary, in his report on the visit to the United States in 1904, refers to the work as follows:

"In regard to the unification of specifications between the two countries, there is no doubt that a closer co-operation between our Committee and the American Society for Testing Materials would lead to a harmonizing of methods of testing, and where the practice permitted it, of specifications. The essential differences in practice existing in the two countries will prevent any complete harmonization of sections and specifications; but there are many points upon which co-operation might be

secured to the mutual advantage of both countries. This could be assisted by more complete interchange of views between the Engineering Standards Committee and the American Society."

MR. C. S. R. PALMER, London, England (communication to the Secretary)*:—The paper contributed by Mr. Colby I understand to be written for the purpose, not of pointing out what is good or bad in the analysis and manufacture of rails, but of drawing attention to points in specifications he has seen which cause needlessly extra expense in manufacture, such expense falling ultimately on the clients of the drawer of the specifications.

It is unquestionable, of course, that some of the safeguards he draws attention to are now unnecessary, because of the possibility of attaining greater certainty in the methods of manufacture. But this advance in certainty of method has been accompanied by the possibility of much greater rapidity of manufacture than previously obtained, with the net result in some cases that enough work, physical and mental, is not put into the rails; and, moreover, there is a third possibility—viz., of work being slurred over, owing to the checks or tests being few.

In this connection, it has to be remembered that a reduction of price on the rails of 10 per cent. at the mills will work out to probably not more than 6 per cent. on the rails laid in the road abroad, and probably not over 2 per cent. of the whole cost of the very cheapest of railways. This small saving would be dearly bought if the life of the resulting permanent-way were at all reduced.

The matter, however, is one of considerable interest to me, and attention is therefore drawn briefly to some main points in Mr. Colby's proposals which would tend to prevent the competition he presses for, since these points, as well as sundry others, either give the manufacturer undesirable latitude or curtail the rights of the purchaser and his engineer to an extent that it would not pay the purchaser to accept.

Taking first that most objectionable element in steel—viz., phosphorus—Mr. Colby urges acceptance of a percentage of 0.10, against 0.07 usually allowed in Europe, and at the same time he also urges reduction of the amount of drop-testing

* Received July 21, 1906.

to one-half of that considered necessary in Europe and by some American railways. It might be possible as a matter of economy to ease one or the other, but surely not both conditions; that is to say, it might be possible to accept the higher phosphorus, but, in my opinion, only when accompanied by a rigid drop-test on a piece from the top of the ingot of every heat—the top, that is, after the specified proportion of the ingot has been discarded. Moreover, acceptance of the higher phosphorus with the carbon-percentage (higher and not lower than Mr. Colby's in the smaller sections) allowed in England would make for the necessity of greater rigidity in adherence to analyses and of not less frequent analyses.

Further, in connection with the quality of the rail, is the question of the finishing-temperature and the amount of work therefore put into the rail. This does not appear to have been touched on in the paper anywhere, and I would be glad of the author's remarks on the point. Assuming too that the temperature is sufficiently low for good work, is not an allowance of $\frac{3}{16}$ in. each way in a 33-ft. rail sufficient for hot sawing?

Moreover, from the point of view of the purchaser seeking economy, there is an objection to his being called on to pay for a greater weight than he contracted to buy. Thus, while it is reasonable to give the manufacturer a rolling-margin both ways in weight, it is hardly right and certainly not economical for the purchaser to take the risk of having to pay for overweight, more especially remembering that 0.5 per cent. excess of cost at the mill means from 0.75 to 1 per cent. excess of cost in the road abroad. Similarly, as regards accepting short rails as part of the tonnage contracted for, it should be remembered that the amount of short rails recommended by the author would mean 1 per cent. extra joints in the line, with, of course, the corresponding extra capital-cost of jointing, and of sleepers, and of maintenance. Yet again, why should the purchaser be called on to accept seconds in addition to the tonnage contracted for? Will it pay him to be left in doubt as to what quantity the manufacturer's methods of work, good or bad fortune, may cause him to be billed for?

Finally, as illustrating a third class of objections, attention is drawn to the proposal to curtail the engineer's powers, and, at the same time, to enter in the specifications such general word-

ing as "The entire process of manufacture and testing shall be in accordance with the best current practice," and "Sufficient material shall be discarded or cropped from the top of all ingots to insure sound rails." There should be some judge in case of dispute between manufacturer and inspector; the purchaser cannot afford to take the risk of expensive arbitrations; hence the English practice of vesting final decision in the specifying engineer, and, so far as my experience gained in three continents goes, the practice does not bear hardly on, or alternatively in favor of, either purchaser or vendor.

MR. ALBERT SAUVEUR, Cambridge, Mass. (communication to the Secretary)*:—The most glaring shortcoming of the rail-specifications reviewed by Mr. Colby as well as of those which he proposes is to be found in their silence on the subject of "discard."

It has become customary in American technical meetings to dismiss this question of discard by some more or less witty jest, but such practice only serves to illustrate the weakness of the position of those resorting to it.

I have repeatedly called the attention of manufacturers as well as of consumers to the very serious danger of rolling "piped" rails, which is the common practice of the day. The pipe extends so far down the ingot that the first rail rolled must, in the majority of cases, be "piped" and, therefore, seriously defective, because of insufficient discard. This fact is, of course, well known to manufacturers, and their fear to have it brought to light in a manner too costly to themselves accounts for their strenuous and so far successful opposition to the introduction in specifications of a clause requiring the drop-test to be applied to the rails corresponding to the tops or piped ends of the ingots. It is not to be supposed that the consumers are not equally well informed regarding the existence of this defect and their failure to insist upon such specifications as would prevent the rolling of piped rails is more difficult of explanation unless it be assigned to their fear of having to pay considerably more for their rails in case of a much larger discard. In the United States, moreover, the financial relations between large railroad companies and steel-works are often so close as

* Received August 31, 1906.

to suggest at least another explanation for their apparent indifference.

So long as so vital a matter is ignored in rail-specifications, I, for one, am unable to take much interest in the refinements suggested in chemical composition, finishing-temperatures, etc., —they certainly appear futile, not to say farcical. It is like trying by ingenious devices to improve the complexion of a patient suffering from a severe organic trouble. Is the game worth the candle? What is needed to save him is a major surgical operation and not the administration of homeopathic and relatively ineffective pills. Continued failure in this respect must result in placing these makers of rail-specifications in the metallurgical branch of a great family of unsavory fame.

M. NIGOND,* Paris, France (communication to the Secretary)†:—The chief difference between the specifications adopted by the company with which I am associated, and those suggested in Mr. Colby's paper, is that my company do not require a specific chemical composition, but, on the other hand, they do specify the tensile strength, with a clause as to the minimum elongation, and also drop-tests and bending-tests.

They consider that chemical determinations, except carbon, cannot be furnished with sufficient accuracy, without retarding manufacturing operations, and it therefore appears safer to judge the metal by the actual results it gives, rather than by its composition. Slight variations in that composition may, as a matter of fact, have an important influence on the strength.

In the case of their rails of 42 kg. per m. (85 lb. per yd.), when it was specified that the test-specimen for tensile should be taken from the portion of the head least liable to wear the required tensile strength was reduced from 70 to 67 kg. per sq. mm. (99,562 to 95,295 lb. per sq. in.) and the minimum elongation from 10 to 8 per cent.

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* The Engineer in Chief of the Paris and Orleans Railroad.

† Received July 20, 1906.

SECRETARY'S NOTE.—Mr. Colby's reply to the above discussion will be published in the *Bi-Monthly Bulletin*, No. 14, March, 1907.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Improvements in Rolling Iron and Steel.

A discussion of the Paper by James E. York, New York, N. Y., presented at the London Meeting, July, 1906, and printed in *Bi-Monthly Bulletin*, No. 9, May, 1906, pp. 337 to 357.

MR. ROBERT W. HUNT, Chicago, Ill.:—It has been my good fortune to know of this development of Mr. York's for some time, and I think he will permit me to say that this is not the first demonstration that he has made of his method for rolling difficult shapes, and which, as he has stated, had in the past been regarded as practically impossible. I have good reason to know that Mr. York has been successful on other lines, because I myself went through a period of professional disrepute for having reported favorably on his methods, which received discredit up to the time that it was practically demonstrated that his claims were true ones. Years ago Mr. York built a mill at Duluth, Minn., for the production of structural shapes, and notably of what might be called balanced beams—beams that did not have flanges of restricted width. His scheme was to produce a beam with flanges so wide that they could be used in place of built-up beams. The mill, of course, went through the difficulties that such a mill would have to encounter. I was called upon to make an examination of the property and report. These beams were rolled on a universal mill—a mill which would admit of various-sized sections without change of rolls. I was convinced that Mr. York could do it, and I so reported. Having received condemnation and ridicule for having taken that position, later on I was glad to find that Mr. John Fritz had come to the same conclusion, and had so reported. I concluded we both could rest content, while awaiting developments. Later still, as we all know, there was another difficulty that Mr. York met with—namely, that the architects or structural engineers would not accept his proposed sections. That is still a great difficulty in America. Later, the Grey mill came into successful operation in Luxemburg, producing such sections, which are being used in England and on the Continent. In fact, the

whole process, both from a commercial and a mechanical point of view, is a success. The Bethlehem Steel Co., Bethlehem, Pa., are putting in a Grey—that is, a York mill, as part of their immense new plant which is in course of construction. Owing to matters over which Mr. York had no control—that is, the financial side of the question—it was taken out of his hands, but it is the York mill that is making the sections. When Mr. York showed me the present examples of his skill, I was quite as much surprised as the company, but I was perfectly prepared to credit his claims.

MR. KURT KERLIN, Düsseldorf, Germany:—I am of the opinion the paper read by Mr. York would have been better if divided into two different parts—*i. e.*, 1. Universal Girder Rolling-Mills; 2. Transverse Mills.

As I have only to-day for the first time heard anything of the latter type of mills, I am not able to say anything about them, but I think this idea of transverse mills, brought before us to-day by Mr. York, must be very interesting.

On the other hand, universal girder rolling-mills are not by any means a new idea, as on May 9, 1889, Mr. Hugo Sack, then of Duisburg, read before the Iron and Steel Institute a paper on universal girder rolling-mills for rolling girders and cruciform sections.[1] He gave in his paper an exact statement of the scientific and technical reasons why the ordinary method of rolling flanged sections in two-high and three-high mills is objectionable. At the same time he exhibited a model of his mill, which had been already working, among other works at those of Messrs. David Colville & Sons, Ltd., and the Newton works of The Steel Co. of Scotland, Ltd., and I take it from the discussion recorded in the proceedings of the year 1889 of the Iron and Steel Institute, that Mr. E. Windsor Richards was present at the discussion, and so that gentleman could corroborate me in what I have said. I may also say that at a later date this model was again exhibited in this country and that there exists another universal mill—the Grey mill—which is already in actual working at Differdingen.

The chief difference between the Grey mill, on the one hand, and the Sack and York mills, on the other, is that the Grey

[1] *Journal of the Iron and Steel Institute*, vol. xxxiv., No. 1, pp. 132 to 151 (1889).

mill has a special pair of horizontal rolls, which are placed at some distance away from the four other rolls, and act especially upon the edges of the flanges, while in the Sack mill this action upon the edges of the flanges is done simultaneously by the four rolls which are lying in the same plane. This is a great advantage and is much simpler when compared with the Grey mill.

As regards the York mill, the manner in which the compression of the flanges upon their edges is performed is not demonstrated in the paper, and from the short notes made by Mr. York, I do not at present see how he intends to roll girders with flanges of an exact width and with the web precisely in the middle of the flanges. I would like very much to hear further from him on this subject.

I am at the same time thankful to Mr. York for drawing the attention of this meeting to the universal system of rolling girders, which system without doubt will be of far greater importance in the future than it has been in the past. In fact, the method now in vogue of rolling girders—*i. e.*, in two-high or three-high mills—is a very crude one, as I will now endeavor to point out.

In order that a rolled bar may pass easily into the next groove, the latter has always to be made somewhat wider than the previous one, and consequently in this way sections are always obtained of increasing width, and it is obvious that under such circumstances no pressure can be exerted upon the outer surfaces of the flanges, and their widths cannot be much reduced. Further, only the inner surfaces lend themselves as a point of attack for reducing their thickness. By this process the rolls must evidently squeeze themselves between the inner surfaces of the flanges, and scrape the material down the inner face of the flange, the edges of the rolls forming there a ridge and accumulating material in the corners. This material must be transplaced laterally across the fiber, thus weakening the tensile strength considerably.

Accordingly one might divide the rolling of a girder in an ordinary mill into three distinct stages, viz.:

1. The rolls come into contact with the flanges and begin to scrape;
2. The material is piled and is displaced laterally;

3. The web takes its form.

Before acting upon the web it is clearly seen that the flanges are nearly fully extended, while the web still preserves its original length, so that this method of rolling cannot do otherwise than produce a great strain in the rolled material, and very great wear and tear to the rolls. Further, this interior strain, produced as described above while rolling, remains in the finished girder. This is more clearly described in Mr. Sack's paper already quoted. In consequence, the ordinary rolled girders, as produced up to the present, are not reliable, as a proof of which I may mention that the web is liable to spring apart suddenly, if one chips away the flanges of a girder produced under the ordinary method. Another great disadvantage is, that at present the flanges must still have a certain amount of taper and are accordingly not parallel. All these important disadvantages are entirely obviated by the Sack universal girder-mill, with which one can produce girders with absolutely parallel flanges, of a thoroughly sound and naturally rolled material, which would be more suitable and reliable for any application than any other girder rolled up to now.

With the mill as described in Mr. York's paper I do not see how it is possible to produce girders with absolutely parallel flanges, as the Sack mill will produce, and I do not see how he prevents the formation of fins, or how he can arrange his mill to operate in any ordinary stand of housings, whereas Mr. Sack's mill can be adapted for an ordinary pair of housings, which can be used either for the ordinary or for the universal system of rolling girders—*i. e.*, with four rolls lying in the same plane.

I am prepared to show the feasibility of this to any gentleman present at the meeting, who may care to visit Mr. Sack's works, near Düsseldorf, where the old model of the year 1888 can be seen working, while I may further mention that Mr. Sack is at present building a universal girder rolling-mill after his system, which I expect will shortly be running.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Heat-Treatment of Steels Containing Fifty Hundredths and Eighty Hundredths Per Cent. of Carbon.

Discussion of the Paper by C. E. Corson, which was presented at the London Meeting, July, 1906. (See *Bi-Monthly Bulletin*, No. 11, September, pp. 725 to 742.)

ALBERT SAUVEUR, Cambridge, Mass. (communication to the Secretary*):—On close examination I think it will be found that the evidence by which Mr. Corson claims to have shown the inaccuracy of a statement I made a few years ago, is far from convincing. This statement is:—

"Hot work, as such, has no influence upon the structure of the metal. Indirectly, however, by retarding crystallization until a lower temperature is reached, it may influence its structure most decidedly; but the same results could be accomplished by heat-treatment alone, i.e., by reheating the unworked metal to the temperature from which the unworked piece was allowed to cool undisturbedly." *The Metallographist*, vol. ii., p. 267 (under the head of "Changes of Structure Brought About by Work").

Of the two pieces of steel tested by Mr. Corson, one was worked and finished at a "cherry red" and the other reheated to a cherry red, and the assumption was made that in both cases the temperature was about 715° C., although no pyrometric device was used to record it. The possibility of considerable difference in temperature alone is so great as to invalidate Mr. Corson's inferences. The apparent temperature, moreover, is so close to the critical point of the steel as to render any conclusion very hazardous. It is not at all evident that the annealed piece was reheated past its critical point, in which case reheating would have had practically no effect. Nor is it evident that the piece forged and finished at a cherry red was not actually below the critical point, which, by definition, I have called cold worked.

Mr. Corson's explanation that "Under proper reheating, on the other hand, the steel becomes a solid solution from which crystals of approximate homogeneity and uniform size may separate" will not be readily understood.

* Received September 12, 1906.

It should be borne in mind that my statement refers to hot work only; that is, the work performed above the critical point, and in that range the steel is in the condition of a solid solution just as well as if it had been reheated to that temperature. In other words, if a piece of steel be worked to 800° C., and allowed to cool slowly, or if it be reheated to 800° and slowly cooled, it will in both cases cool undisturbedly from the condition of a solid solution.

In view of the above explanation, the statement which Mr. Corson criticises cannot be set aside in the light of a single experiment, especially since that experiment is so crude, and the results so uncertain, as to cause its significance to dwindle into insignificance.

Aside from the discussion, Mr. Corson should be congratulated on the excellence of his photomicrographs.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Constitution of Mattes Produced in Copper-Smelting.

A Discussion of the Paper by Allan Gibb and R. C. Philp.[1]

ALLAN GIBB, Queensland (communication to the Secretary[2]):—It is gratifying that Mr. Edward Keller,[3] who has done so much work elucidating the principles of copper metallurgy, should have subjected only that portion of our investigation relating to magnetic iron oxide to anything like adverse criticism.

Situated as we were on a mining camp, it was impossible to undertake work that would cover all the intricate possibilities connected with the materials commonly classed as matte. We therefore began the investigation on matte produced from ores that contained no other components than the sulphides of copper and iron that would be likely to enter into the composition of matte. We were, accordingly, free from any possibility of magnetic iron oxide entering the matte, unless it were formed in the operation itself. The work done on this subject was incomplete, and the results thereof recorded as giving only negative evidence as to the absence of magnetic iron oxide. It would have been better to have left the matter open, as "not proven." The trend of the investigation was to account for the insufficiency of sulphur in matte to satisfy the requirements of ferrous and cuprous sulphides. So far as our deductions are correct, it was unnecessary to consider the (in our samples) somewhat doubtful constituent, magnetic iron oxide.

The mattes that were investigated were among those mentioned by Mr. Keller, "which scarcely show any magnetic properties." The samples showed no such properties. There was no unaccountable variation in the specific gravity, which only varied, as would be expected, with the proportion of ferrous sulphide. I have had experience in smelting ores of which the gangue was a siliceous magnetite, both in blast- and rever-

[1] *Trans.*, xxxvi., pp. 665–680 (1906).

[2] Received August 4, 1906.

[3] *Trans.*, xxxvi., p. 837 (1906).

beratory furnace. The mattes so produced contained magnetic iron oxide, sometimes as much as 7 per cent. of iron being present in this form. On treating such mattes with oxidizing solvents, the proportion of magnetic iron oxide varied somewhat with the solvent used, but a fixed proportion was obtained when concentrated sulphuric acid was mixed with the solvent. This residue could be dissolved only after fusion with fusion-mixture. Upon resmelting these mattes in blast-furnaces, in which the volume of blast was largely in excess of that required to oxidize the carbonaceous fuel, the proportion of insoluble magnetic iron oxide was reduced. Apparently, even under highly-oxidizing furnace-conditions, magnetic iron oxide is decomposed presumably by silica and sulphides. I have seen magnetic iron oxide crystals produced in a furnace smelting erratically, but I am of the opinion that normal work, whether reducing or oxidizing, does not tend to form this compound.

I do not grant to "*das Chemische Gefühl*," nor to chemical precedent, the all-embracing infallibility apparently expected by Mr. Keller. Chemical investigation, exactly as with metallurgical, has for its object the elucidation of certain phenomena under certain conditions, and there are innumerable chemical reactions that are modified or entirely reversed by varying the conditions. A case somewhat similar to that to which Mr. Keller takes objection caused me trouble some years ago. According to records, metallic iron will precipitate antimony from solution without having the same effect upon tin. This difference constitutes a rough analytical separation for the two metals. Under certain conditions of saturation this separation breaks down, tin being precipitated almost as readily as antimony. Returning to the reaction under criticism, I have obtained products from the direct fusion of pure sulphides of copper and iron in crucibles that do and do not give residues of magnetic iron oxide when treated with nitric acid and potassium chlorate. As regards the solubility of the magnetic oxides of iron assumed to be precipitated by the oxidizing solvent, it is not uncommon that an ignited precipitate is quite unacted upon by solvents that readily dissolve the precipitate before ignition. This may, as suggested by Mr. Keller, be due to change in molecular segregation.

Mr. Keller appears to have given greater prominence to this subject than we intended for it. That magnetic iron oxide may be held, either chemically or physically, by mattes is undoubted, but its presence is not explanatory of the fact that the proportion of sulphur in mattes is less than that required to satisfy the requirements of the copper and iron. Further, I consider that when complex mattes are treated with oxidizing solvents, part of the iron may, under conditions at present unknown to me, be converted into magnetic iron oxide.

Referring to the magnetic properties of solid solutions of iron in ferrous sulphide, the saturated solutions are strongly magnetic, whereas as much as 15 per cent. of iron may be added to ferrous sulphide before the solid solution becomes feebly magnetic.

Mr. Philp is at present in London, and I have had no opportunity of discussing the criticism with him. The foregoing will, accordingly, represent my personal views of the matter.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Secondary Enrichment of Copper-Iron Sulphides.*

A Discussion of the Paper of T. T. Read, presented at the Bethlehem Meeting, February, 1906, and printed in the *Bi-Monthly Bulletin*, No. 8, March, 1906, pp. 261 to 268.

E. C. SULLIVAN, Washington, D. C. (communication to the Secretary†):—Mr. Read's paper is deserving of high commendation for attacking the problem from the experimental side, yet certain errors have crept into the work to which it seems desirable to direct attention. Most serious of these is the fact that in the two experiments in which data are given, showing the total quantities and composition of solid and solution before and after the experiments, there are discrepancies great enough to deprive the results of significance.

In Experiment No. 1 the author has, before the experiment:

10 g. of chalcopyrite containing	3.262 g. of copper and	2.724 g. of iron.
100 cc. of solution containing	0.360 g. of copper.	......
Total,	3.622 g. of copper and	2.724 g. of iron.

At the conclusion of the experiment:

9.54 g. of chalcopyrite containing	3.234 g. of copper and	2.563 g. of iron.
100 cc. of solution containing	0.338 g. of copper and	0.343 g. of iron.
Total,	3.572 g. of copper and	2.906 g. of iron.

There is an apparent gain of 0.182 g. of iron, while solid and solution are each made to lose copper; the error, 0.050 g., being more than twice as great as the amount of copper (0.022 g.) which the author concludes was precipitated from solution by the chalcopyrite.

In Experiment No. 3, in which data are given for making the calculation, there are similar discrepancies, the iron appearing to increase from 2.724 to 2.827 g., and the copper to decrease from 3.262 to 3.241 g.

* Published by permission of the Director of the United States Geological Survey.

† Received June 12, 1906.

The data as given by the author indicate on their face that the precipitation of copper from cupric sulphate solution by chalcopyrite is greater in absence of sulphurous acid, a result not in keeping with the work of A. H. Winchell,[1] which seemed to show that the reaction between pyrite and cupric sulphate was facilitated by the presence of sulphurous acid. In experiments made by me to test this point, cupric sulphate solution (40 cc. containing 0.1 g. of copper) saturated with sulphur dioxide lost its color almost at once on shaking with 20 g. of finely powdered chalcopyrite, while cupric sulphate without sulphur dioxide, similarly treated, became colorless only at the expiration of a week. To each of the colorless solutions 4 cc. of a cupric sulphate solution was then added, containing 0.250 g. of copper. On standing over night, the solution containing sulphurous acid was again colorless, while the color in the other faded very slowly. In similar experiments with pyrite and cupric sulphate in presence and in absence of sulphurous acid, the copper at the end of three days had been practically removed from the solution which contained cupric sulphate and sulphurous acid, while from the solution which contained cupric sulphate alone about 0.040 g. of copper had been precipitated out of a total of 0.097 g. of copper in 40 cc.

There seems, therefore, to be no doubt that sulphurous acid accelerates the precipitation of copper, presumably as sulphide, from cupric sulphate solution by pyrite and chalcopyrite. The fact should be emphasized, however, that the presence of sulphurous acid is by no means essential to the precipitation of copper from cupric sulphate solution by these sulphides. Indeed, it may be open to question whether, so far as the quantity of copper precipitated is concerned, the difference caused by the presence of sulphurous acid is great enough to be of significance to the geologist.

Only one other point will be mentioned. The work of Morgan and Smith,[2] cited by Mr. Read as demonstrating that chalcopyrite is a cupric ferrous compound (CuS, FeS) rather than a cuprous ferric (Cu_2S, Fe_2S_3) seems not to be perfectly conclusive. Morgan and Smith, on passing hydrochloric acid gas

[1] *Bulletin of the Geological Society of America*, 14, p. 269 (1903).

[2] *Journal of the American Chemical Society*, 23, p. 107 (1901).

over the mineral, and treating the residue with water, obtained a solution which reduced permanganate in the quantity to be expected if the iron were ferrous. Inasmuch, however, as cuprous chloride and ferric chloride may react to form cupric and ferrous chlorides, it would appear that the result might be the same whichever of the two formulas were correct.[3]

T. T. READ, Colorado Springs, Colo. (communication to the Secretary*):—The discrepancies to which Mr. Sullivan adverts had not escaped observation; but the comparison he makes is somewhat unfair, as the errors lie in the determinations on the solid residue (it was not possible at the time to make them as carefully as was desirable), while the inferences as to the action which had taken place are properly drawn from the composition of the solution.

The chalcopyrite used for the original experiment was absolutely pure, no foreign material could be detected by most careful microscopic examination. Upon repeating the experiment upon ordinarily clean chalcopyrite, containing small amounts of other sulphides, results were obtained which agree with the experience of Messrs. Sullivan and Winchell. It would seem, then, that, under ordinary circumstances, the presence of sulphur dioxide accelerates the precipitation of copper from a solution of the sulphate.

In regard to the strictures upon the work of Morgan and Smith, it seems only logical to inquire, since the ferric and cuprous salts react upon the decomposition of the mineral to form ferrous and cupric salts, why they should not have similarly reacted at the instant of formation of the mineral. Allan and Gibb, and, more recently, Röntgen, have shown that intermetallic compounds of cuprous and ferrous sulphides exist in mattes. It would seem more reasonable to suppose that chalcopyrite is an intermetallic compound of cupric and ferrous sulphides rather than of cuprous and ferric sulphides, especially since the latter is not known as a product of natural reactions.

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[3] Cf. Stokes, *Bulletin No.* 186, *U. S. Geological Survey*, p. 45 (1901).

* Received September 28, 1906.

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OF

The American Institute of Mining Engineers.

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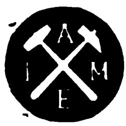

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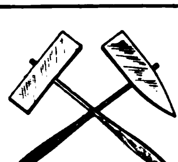

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THE AMERICAN INSTITUTE OF MINING ENGINEERS has adopted no official badge, the possession of which is proof of membership. Numerous designs, however, have been executed for temporary use, and of these the three here shown have proved so convenient and attractive that many members continue to wear them as personal ornaments. To this there is no objection; and these badges will be sent postpaid to Members and Associates on the receipt of the price by New York check, or Postal Money Order, in favor of the Secretary, as follows:

Blue Enameled Button, silver, \$0.75; gold, \$2.50; White Enameled Button for officers, gold, \$2.50; Cross-Hammers, gold, \$2.75; Seal Watch-Fob, silver-gilt, \$2.50; silver, \$4.00; gold, \$1 to \$20.

. 14. MARCH. 1907.

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INSTITUTE ANNOUNCEMENTS.

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For the year ending February, 1908.

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* SECRETARY'S NOTE.—The Council is the professional body, having charge of the election of members, the holding of meetings (except business meetings), and the publication of papers, proceedings, etc. The Board of Directors is the body legally responsible for the business management of the Corporation, and is therefore, for convenience, composed of members residing in New York.

BI-MONTHLY BULLETIN.

ɔr the convenience of persons who desire to file, or other- use separately, the technical papers in Section II. of the etin, each of these papers has been paged and wired by ; the whole collection being held together by a single, y wire, upon the removal of which it will fall apart into idual pamphlets, substantially like those formerly issued.

small stock of separate pamphlets, duplicating the tech- papers given in Section II. of this Bulletin, is reserved for who desire extra copies of any single paper.

l communications concerning the contents of this Bulletin d be addressed to Dr. Joseph Struthers, Assistant Secre- and Editor, 29 W. 39th St., New York City (Telephone ɔer 4600 Bryant).

UNITED ENGINEERING SOCIETY BUILDING.

As already stated in *Bi-Monthly Bulletin*, No. 13, January, 1907, the Institute has occupied its offices in the new building since December 26, 1906; and request is again made that all communications and other mail matter for the Institute, or its officers, be addressed to "Engineering Society Building, 29 West 39th St., New York, N. Y."

An illustrated pamphlet, giving a full description of this building, is being prepared by a committee of the United Engineering Society, for distribution at the dedication exercises, April 16, 1907. This description, in full or in part, will be republished in *Bi-Monthly Bulletin*, No. 15, May, 1907.

Circular No. 2, dated March 16, 1907, gives further details concerning the meeting of the Institute, which will be held directly following the dedication and formal opening of the building. The sessions for the reading and discussion of papers, April 18 and 19, will be held in the main auditorium. More than forty papers have been received for presentation, of which a preliminary list is given in Circular No. 2. A complete list will be printed later in the program of the Local Committee, to be given to members on registration and to others upon written request to the Secretary.

It is earnestly desired that members will make extra efforts to be present at this the Institute's first meeting in its new home.

LIBRARY.

The library of the Institute has now been moved from 99 hn Street to the new Engineering Society Building, and is ailable for limited use. The official opening of this library gether with the libraries of the American Society of Mechanl Engineers and the American Institute of Electrical Engiers, has been deferred until all the books shall have been ssified and arranged and all library material fully indexed. e notice of the official opening will be given either by a circu- letter or by notice in a later issue of the *Bi-Monthly Bulletin.*

Accessions.

Owing to the great amount of work involved in moving the ire library, it has not been practicable at this time to arge a list of accessions of books for the period Jan. 15 to r. 15, 1907. A complete list of accessions from Jan. 15 to y 15, 1907, however, will be published in *Bi-Monthly Bulletin*, . 15, May, 1907. Among the books received are two which ve been reviewed, and in order to present these reviews in ely season they are here published.

gineering News Publishing Co.

KETCHUM, M. S. *The Design of Steel Mill Buildings and the Calculation of Stresses in Framed Structures.* Edition 2, xiv, 464, 16 p. il., 8vo. New York, 1906.

SECRETARY'S NOTE.—Although the title of this book apparently confines it nly to mill-buildings, its value has a much wider range. It might almost be said the sub-title is more important than the title. For the recent employment of steel etons in the construction of buildings has reached already so large an extent, and nises to grow so enormously and rapidly larger, that intelligence in this departt is imperatively required on the part of designing engineers and contractors. h edifices, properly proportioned and protected, have shown, so far, a high dee of strength and probable permanence; but it does not follow that anybody can gn and erect a steel-frame building by "rule of thumb," or by the simple oldioned method of imitating some other building, or by assuming that anything le of steel is sure to be "strong enough." And there is reason to fear that more ess reckless construction of this class has already taken place, through the ignot audacity of architects and the ignorant tolerance of municipal departments. Mr. chum's treatise, therefore, may be highly useful for the instruction of builders

and the protection of the public in a sphere wider than that which he modestly professes chiefly to cover.

The book is divided into four parts, treating respectively of Loads, Stresses, The Design of Mill-Buildings, and Miscellaneous Structures; and there are two Appendixes, on Specifications and Problems in Graphic Statics and The Calculation of Stresses. The topics under each head are treated with clearness and fullness; and the typography and illustrations are creditable to the publishers.—R. W. R.]

D. Van Nostrand Company.

TINNEY, W. H. *Gold-Mining Machinery*, xii, 308 p. il. pl. 8vo. New York, 1906. Price, $5.00 *net.*

[SECRETARY'S NOTE.—Mr. Tinney's book is offered to meet an unquestionable and general want. The rapid advance in the department of mining-machinery, as well as in all other departments of mine-engineering, makes it highly important that engineers should be posted concerning the latest improvements. And, in fact, information of this sort relating to foreign machinery and methods is more desired by American mining engineers than that which concerns our own plant and practice and is easily accessible in the catalogues of American manufacturers. Mr. Tinney, whose experience has been in other countries, mentions chiefly foreign apparatus; but much of the information given by him is equally applicable to all machines. The book contains chapters on motive power (steam, hydraulic and electric), the erection of engines; boilers, chimneys, fuel and feed; the management of motive power; pumping-machinery; winding-machinery; air-compressors; rock-drills; crushing-machinery; concentrating and gold-extracting plant; the transmission of power; transportation; piping and joints; the construction of buildings; tackle and tools; and details for estimates, besides many miscellaneous tables and formulas of use to engineers.—R. W. R.]

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1887.	*Thomas T. Baker,	April 30, 1906.
1874.	*George L. Bradley,	March 26, 1906.
1898.	*George H. Evans,	February 4, 1907.
1886.	*A. W. Fiero,	July 28, 1906.
1893.	*William W. Garrett,	January 14, 1907.
1900.	*Christopher Henne,	December 12, 1906.
1872.	*Winfield S. Keyes,	December 27, 1906.
1892.	*Gustavus W. Lehmann,	August ——, 1906.
1882.	*William H. Long,	October 27, 1906.
1872.	*William G. Neilson,	December 29, 1906.

* Member.

HANGES OF ADDRESS OF MEMBERS.

e following changes of address of members have been ved at the Secretary's office during the period of Jan. 1 to 15, 1907. This list therefore supplements the annual list embers corrected to Jan. 1, 1907, and brings it up to the of Mar. 15, 1907. The names of members who have acd election during January and February, 1907 (new mem-, are printed in *italics*.

e large number of changes of address since Jan. 1, 1907, s the importance of publishing these changes as frequently ssible, and the *Bi-Monthly Bulletin* has been selected as the s to present this information to the members of the Insti- By a simple method of cutting out these names and ades and pasting them directly over the corresponding names e annual list of members, the record can be kept pracy up to date, and the value of the list correspondingly ined. For this purpose the changes of address have been ed only on one side of the page. The names of new membeing in italics, are readily distinguished from the others, can be pasted in approximate alphabetical order on the ins of the pages.

T, CLARENCE E., Chief Engr., Iron Mines Div.,
Tennessee Coal, Iron & R.R. Co., Bessemer, Ala.
, WILLIAM........Apartado 122, Chihuahua, Mexico.
, WILLIAM H........Box 209, Portland, Oregon.
RS, RUDOLF O........Sandar Mines, via Hospet S. M. Ry., South India.
ERRE, RAFAEL F........San Felipe, Guanajuato, Mexico.
NDER, CURTIS........Paisley, Lake County, Oregon.
, *Charles E. Le N.*, Min. Engr........Box 326, Park City, Utah. '06
D, LEO F........Sultepec, Mexico.
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-*Turenne, Raymond*, Min. Engr........605 3d Ave., Seattle, Wash. '06
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, HENRY J. B........Bayamo, Cuba.
AY, THOMAS H........Casilla 18d Santiago, Chili, South America.
EN, HENRY A........1861 E. 93d St., Cleveland, Ohio.
ON, CHAS. E. W........145 W. 58th St., New York, N. Y.
ER, FRANCIS K., Jr........Hawthorne, Nev.
ES, FREDERICK P........615 S. Maple St., Trinidad, Colo.

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rn, William H., Supt. of Mines, Care Tonopah Belmont
Development Co., Tonopah, Nev. '06
llen F., Chief Engr. of Construction, Northwestern
Improvement Co., Tacoma, Wash. '06
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A. A..Hotel Belmont, New York, N. Y.
UX, ALBERT F. J.......................Care Post Office, Mexico City, Mexico.
RD, ROBERT S., Compania general de Mines, Cruz del Eje,
Cordova, Buenos Ayres, Argentine Republic, South America.
ALEXANDER...........................Juanita Coal & Coke Co., Somerset, Colo.
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, WILLIAM M..20 Orange St., Asheville, N. C.
FREDERICK J...............................Apartado 714, Mexico City, Mexico.
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OTT, WILLIAM A...............P. O. Box 1167, Johannesburg, South Africa.
s, Adolfo, Mine Supt.........Puntarenas, Costa Rica, Central America. '06
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NG, ROSCOE H., JR., Prest. Cerro de Pasco Mining Co.,
of Peru, 15 Broad St., New York, N. Y.
AN, JAMES E., Engr., Minas Dolores y Anexas of the
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ALBERT LADD.............................217 W. 110th St., New York, N. Y.
AN, R. PEWITT........................505 Union Trust Bldg., Los Angeles, Cal.
S, FREDERICK, The Cerro de Pasco Mining Co.,
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V. ROWLAND.............................Apartado 137, Aguascalientes, Mexico.
CHARLES E.......................Apartado 21, Sombrerete, Zacatecas, Mexico.
, R. A.........Care John M. Keith, San José, Costa Rica, Central America,
, LEONARD C..Wilmington, Del.
, *Cecil H.*, Min. Engr., Care C. W. Cropper,
Mining Exchange Bldgs., Kalgoorlie, Western Australia. '06
THOMAS B., Assayer and Chem...........1109 E. 13th Ave., Denver, Colo.
ngs, W. L., Geol. and Min. Engr., 917 Delaware Ave.,
South Bethlehem, Pa. '06

INGS, WILLIAM N....................................422 Roe Bldg., St. Louis, Mo.
, *Percy W.*, Min. Engr., Mgr., Paducah Bullfrog G. M. Co.,
Box 201, Rhyolite, Nev. '06
ÁLBERT C., Min. Engr............................Cactus Mine, Newhouse, Utah.
, *William A. T.* (Entered in January list under Davis),
Sub Mgr., Queen Margaret Gold Mines, Bulong, Western Australia. '06.
Y, CHARLES C....................................2805 Kelsey Ave., Berkeley, Cal.
n, *Archibald A. C.*, Min. Engr., Asst. Genl. Mgr., The Dickson
Irwin (Kodarma) Mica Mining Syndicate, Ltd., P. O. Rejoulie, via
Nawadah, E. I. Ry., Gaya District, Lower Bengal, India. '06
, JAMES T........................Abosso G. M. Co., Ltd., Tarkwa, West Africa.
JOHN R..High St., Dunedin, New Zealand.
HUE, PATRICK J., Mgr. and Director, Talisman Mining Co.,
309 D. F. Walker Bldg., Salt Lake City, Utah.
LASS, ROSS E...............Care R. A. Thomas, 43 Wall St., New York, N. Y.
EON, NORMAN M., Genl. Mgr., Victorian Cornish G. M., Ltd.,
and the Daylesford G. M., Ltd., Daylesford, Victoria, Australia.
AN, GUSTAVUS A...Nelson, Lincoln Co., Nev.
AM, LEWIS A..42 Broadway, New York, N. Y.
IN, DAMON D..R. F. D. No. 5, Neosho, Mo.
HT, ARTHUR S.......................................25 Broad St., New York, N. Y.
N, HARRY D., Min. Engr., Div. Engr.........Dering Coal Co., Hymera, Ind.
RDS, WILLIAM S....................................74 Broadway, New York, N. Y.
CH, WALTER L., Supt..................Bonanza Belt Copper Co., Johnson, Ariz.
S, ANTON...751 St. Mark's Ave., Brooklyn, N. Y.
ER, EMANUEL.. ...Instructed to hold all mail.
, WILLIAM J...Wickham, W. Va.
M, ALBERT S..................................Apartado 24, Mexico City, Mexico.
Howard L., Cons. Engr...........................Oaxaca, Oaxaca, Mexico. '06
SON, EDWARD H., Central Chili Copper Co., Panulcillo,
Ovalle, Coquimbo, Chili, South America.
LHARDT, ERNEST C., Supt...The Hercules Gold Mines Co., Deadwood, S. D.
ISH, NORRIS........................305 Union Savings Bank Bldg., Oakland, Cal.
, *Frederick G.*, Min. Engr................517 Cooper Bldg., Denver, Colo. '06
, E. NELSON, Pellew, Harvey & Fell, 62 London Wall,
London, E. C., England.
TSON, HENRY G......................Mining Bureau, Manila, Philippine Islands.
TSON, JOHN L., Public Accountant and Auditor,
1632 N. 15th St., Philadelphia, Pa.
AU, JOHN J. C.............Valverde del Carmine, Provincia de Huelva, Spain.
, FREDERICK M.............Montgomery-Shoshone Mines Co., Tonopah, Nev.
AY, JAMES RALPH....................Room 318, 71 Broadway, New York, N. Y.
ES, PAUL R...15 William St., New York, N. Y.
AR, EDOUARD L.....................................2090 Fell St., San Francisco, Cal.
CK, ROBERT P...................................3035 Flora Ave., Kansas City, Mo.
, *Thomas*, Chem.................................604 Ave. E., Bayonne, N. J. '06
ES, AMBROSE P., Genl. Supt............Dayton Coal & Iron Co., Dayton, Tenn.
IN, CHARLES J., Genl. Mgr., Green Mountain Mining & Milling Co.,
Howardsville, Colo.
AM, JOSEPH P., Nevada Cons. Copper Co.......................................Ely, Nev.
AR, HARRY W. C.. ...Ballarat, Inyo Co., Cal.
HEGAN, ROBERT H. (entered in Jannary list as GEOGHEN),
Minas de Rio Tinto, Provincia de Huelva, South Spain.

ERT, RICHARD M........... ....P. O. Box 1020, Tonopah, Nev.
HRIST, JOHN D.......................................1405 Downing St., Denver, Colo.
ETTE, H. P., Cons. Engr...............1117 Park Row Bldg., New York, N. Y.
ULT, EDMUNDO, Min. Engr..............Ave. Prim 1426, Mexico City, Mexico.
SBROOK, CLARENCE I., Mine & Smelter Supply Co.,
42 Market St., San Francisco, Cal.
ALE, STEPHEN L., Cons. Min. Engr.................Lander, via Beowawe, Nev.
WIN, ROBERT H., Care C. W. Whittall & Co.,
Karabournau Mine, Symrna, Turkey.
ON, ERNEST.........9 St. German Place, Blackheath, London, S.E., England.
ILY, SAMUEL J., Cerro de Pasco Mining Co.,
La Fundicion, Peru, South America.
TY, J. SHARSHALL, Maryland Geological Survey.................Baltimore, Md.
ES, McDOWELL...................... ....Villaldama, Nuevo Leon, Mexico.
, EDWIN F., Great Northern Development Co....................Valdez, Alaska.
SON, WILLIAM H.................................39 Mackay St., Montreal, Canada.
FIN, FRANK W.............................Monadnock Bldg., San Francisco, Cal.
s, George, State Mineralogist,
Cor. Liberdad and Juarez Sts., Chihuahua, Mexico. '06.
E, INDEPENDENCE....................... ......Palace Hotel, Guadalajara, Mexico.
ield, R. A.......................28 Hertford St., Mayfair, London. W., England.
, BENJAMIN M........... ....Trust Bldg., El Paso, Texas.
ILTON, WALTER R...Box 141, Palo Alto, Cal.
MER, WILLIAM L., Genl Mgr., Otter River Stone Co........Lynch Station, Va.
kel, Robert S., Civil Engr. and Mine Surveyor,
San José, Costa Rica, Central America. '06.
KS, ABBOT A................................425 Washington St., San Francisco, Cal.
SON, RASMUS................ ....Silverton, Colo.
raves, Ernest P., Met., Peak Hill Gold Field, Ltd.,
Peak Hill, Western Australia. '06.
RIS, WILLARD F., American Smelters Securities Co.,
Apartado 137, Aguascalientes, Mexico.
ison, William S., Min. Engr., The San Francisco del Oro Mines, Ltd.,
Parral, Chihuahua, Mexico. '06.
T, PHILIP E., Mech. and Elect. Engr. (relative to Mining),
Care Allis-Chalmers-Bullock Co., Construction Dept., Montreal, Canada.
H, FREDERICK H.....................Cowley Place, Cowley, Middlesex, England.
, ALEXANDER M.......................................Haileybury, Ont., Canada.
ES, LALON F., Miner, Morning Mine, Federal Mining & Smelting Co.,
Carson, Idaho.
, ELMER C................... ....1209 Prospect Ave., El Paso, Texas.
LER, MARTIN J......................................1199 Post St., San Francisco, Cal.
M, J. D.. ..Apartado 1277, Mexico City, Mexico.
RY, JOHN L..................................720 North Hunter St., Stockton, Cal.
NANDEZ, MARCOS F., Cons. Engr............Bolivar No. 85, Monterey, Mexico.
R, HIERO B., Cons. Engr..........................Monadnock Bldg., Chicago, Ill.
E, HERMAN V., Genl. Supt., The Consolidation Coal Co.........Frostburg, Md.
, WALTER H..................................P. O. Box 342, Cobalt, Ont., Canada.
LER, EDWARD..........................516 Brown-Marx Bldg., Birmingham, Ala.
S, VICTOR G., Hills & Willis, Cons. Min. Engrs.,
318 McPhee Bldg., Denver, Colo.
IAN, B. C................Heathfield, 48 Sydenham Hill, London, S.E., England.

BROOK, CHARLES T., Care Hatfield & Hilles, Real Estate Trust Bldg., Philadelphia, Pa.
s, *Geoffrey C.*, Min. Engr., Mina de San Domingos......Mertola, Portugal. '06.
E, DOUGLAS R., Dept. of Mines, Ministry of Finance.............. Cairo, Egypt.
BARD, HARRY J...Marfa, Texas.
BARD, LUCIUS L., Winona Copper Co..............................Houghton, Mich.
PHREY, CHARLES................. 5 Hamilton Park, New Brighton, S. I., N. Y.
TLEY, DWIGHT B.............. ....31 Bella Vista Ave., Oakland, Cal.
CHINSON, RANDOLPH B., Care Robinson House............Chihuahua, Mexico.
ER, CHARLES A.................158 Southwest Temple St., Salt Lake City, Utah.
S, MURRAY, Cons. Min. Engr..............218 Kohl Bldg., San Francisco, Cal.
DES, S. A..............................414 Mining Exchange Bldg., Denver, Colo.
ES, ALFRED............................2 Broad St. Place, London, E. C., England.
RETT, JOHN, Standard Fire Brick Co..........12 Empire Bldg., Pittsburg, Pa.
VIS, ROYAL P... ....500 W. 123d Street, New York, N. Y.
KS, ARTHUR W., Min. Engr. and Met................................Riverside. Cal.
NSTON, FRED. L...P. O. Box 1469, Bisbee, Ariz.
ston, J. Frank, Blast-Furnace Dept., Bethlehem Steel Co., 34 North Centre St., Bethlehem, Pa. '06.
S, FAYETTE A., Cons. Min. Engr., Room 4, Armijo Bldg., Albuquerque, New Mexico.
ON, JOHN N..............Room 401, Broad Exchange Bldg., New York, N. Y.
DING, CHARLES D., Oriental Cons. Mining Co.... ....Chittabalbie, Korea.
ling, Henry B., Cons. Engr., Mine Mgr...........Cosala, Sinaloa, Mexico. '06.
DA, REIJI, Cons. Min. Engr........18 Nakatomezakacho Koishikawaku, Japan.
SER, ROBERT LEE, Genl. Mgr., Teziutlan Copper Mining & Smelting Co., Cosileo Viejo 24, Mexico City, Mexico.
NEDY, EUGENE P., Min. Engr..............27 Seventh Ave., San Francisco, Cal.
NEDY, GEORGE A..................................2741 Boulevard F., Denver, Colo.
R, MARK B., Montana-Tonopah Mining Co., etc...................Tonopah, Nev.
, LOCHIEL M., Assayer and Chem..............1605 Walnut St., Alameda, Cal.
KCALDY, NORMAN M...54 Elgin Mansions, Maida Vale, London, W., England.
MT, A. J., Supt., Ali Baba Mining Co................................Rhoylite, Nev.
NE, RALPH C...La Jolla, San Diego Co., Cal.
GHT, EDWARD C...........................Apartado 137, Aguascalientes, Mexico.
X, ROGER C...Tonopah, Nev.
TZEN, THEODORE, Supt., The Great Bras d'Or Gold Mining Co., Baddeck, Victoria County, Cape Breton Island, Nova Scotia.
G, JOHN......... ....Charleston, W. Va.
RD, GEORGE A., Smith & Laird, Cons. Engrs.........................Bisbee, Ariz.
B, MARK R.......................................Wood's Hotel, Guanajuato, Mexico.
DERS, WILLIAM H..........................Hotel St. Francis, San Francisco, Cal.
E, HENRY M., Foundry and Met. Engr., 1137 Schofield Bldg., Cleveland, Ohio.
, WILL P., Care Kennedy & Lass, Assaying and Surveying, Greenwater, Colo.
RENCE, H. L...........................118 Burnt Ash Hill, Lee, Kent, England.
, HENRY C..P. O. Box 156, Telluride, Cal.
ie, R. G. Edwards.....................P. O. Box 355, Cobalt, Ont., Canada. '91.
RICHARD HENRY, Blast Furnace Supt., Penna. Steel Co..........Lebanon, Pa.
R, I. WAYNE VON......................................52 Front St., New York, N. Y.
GLE, EDWARD M...............................110 W. 57th St., New York, N. Y.
NARD, R. W...St. Catharines, Ont., Canada.
s, Robert S., Assayer and Engr.....Care Warrior Copper Co., Globe, Ariz. '06.

AY, LIONEL, El Oro Mining & Railway Co.........Apartado 36, El Oro, Mex.
y, *William H.*, Mgr., Nipissing Mining Co., Ltd...Cobalt, Ont., Canada. '06.
, ERNEST DU B ....Ica via Pisco, Peru, South America.
RTHY, M. E., Globe Consolidated Copper Co..........................Globe, Ariz.
RYSTAL, JOHN HENRY.................. Hotel East Fifth, Salt Lake City, Utah.
nb, *Hoyt S.*, Coal Mining Engr., Supt. Coahuila Coal Co.,
Hondo, Coahuila, Mexico. '06.
vitt, *James E.*, With Ohio Steel Works & Furnaces,
280 Custer Ave., Youngstown, Ohio. '06.
UGALL, WALLACE.....20 Bedford Place, Russell Square, London, W.C., Eng.
EN, SAMUEL ....Fedney House, Old Catton, Norwich, England.
ONALD, JOSEPH, Guanajuato Consolidated M. & M. Co.,
Apartado 33, Guanajuato, Mexico.
AY, ANGUS....................................Coppermount, via Ketchikan, Alaska.
ENNAN, FRANK W., Cerro de Pasco Mining Co., Lima, Peru, South America.
OLMSON, JAMES W.......................Room 1, Bryant Bldg., Kansas City, Mo.
EY, HENRY L.....................................1010 Boylston Ave., Seattle, Wash.
H, RICHARD..107 S. Wall St., Spokane, Wash.
, RUSSELL T., Blue Bell Mine..Mayer, Ariz.
EWS, EDWARD J................................ 411 Lowman Bldg., Seattle, Wash.
ERN, HERMAN................................2304 Telegraph Ave., Berkeley, Cal.
ELL, JNO. W. C..............Room 16, 502 California St., San Francisco, Cal.
, JAMES H......Care Henry S. Washington, 95 Liberty St., New York, N. Y.
ILL, EDWARD P., Mgr., Compania de Real del Monte y Pachuca,
Pachuca, Hidalgo, Mexico.
IMAN, MANSFIELD, Cons. Civil Engr..........45 Broadway, New York, N. Y.
ON, REGINALD B..Raton, New Mexico.
EN, JOHN D., Asst. Genl. Mgr., Mt. Bischoff Mine........Waratah, Tasmania.
ER, CHARLES L.....................................828 Frick Bldg., Pittsburg, Pa.
, LOUIS D., Met. Engr., Homestake Mining Co.................Deadwood, S. D.
berger, George, Surveyor...............................Philipsburg, Montana. '06.
HELL, GEORGE....... ....52 Wall St., New York, N. Y.
HELL-ROBERTS, J. F.....................Room 92, 45 Wall St., New York, N. Y.
LL, JOSEPH T...3227 Iowa Ave., St. Louis, Mo.
, WILLARD V..Aguascalientes, Mexico.
ON, ERLE D......................................4557 Brooklyn Ave., Seattle, Wash.
OCH, JAMES V. B...................................Le Campora, Florence, Italy.
AY, CHARLES B., Crowell & Murray, 407 Perry-Payne Bldg., Cleveland, Ohio.
AY, JAMES J., Southwest Smelting & Refining Co...Orogrande, New Mexico.
L, FRANK J...2335 Stout St., Denver, Col.
ANN, DR. EDMUND, Tellus Actiengesellschaft für Bergbau und
Hüttenindustrie, Frankfort-on-Main, Germany.
ls, John C., Min. Engr., Supt. Oriental Cons. Mining Co.,
Chittabalbie, Korea. '06.
OLS, HORACE G., Mgr. Ymir Gold Mines, Ltd.............Ymir, B. C., Canada.
EDWARD A., Mine Supt. New York & Honduras Rosario Mining Co.,
San Juancito, Honduras, Central America, via New Orleans.
NEZ, EZEQUIEL.........Avenida General Prim No. 1245, Mexico City, Mexico.
M, THOMAS H., Genl. Mgr., The Arizona Smelting Co........Humboldt, Ariz.
TER, ROBERT K., Mgr. San Carlos Copper Co., San José, Tamaulipas, Mexico.
ER, EDWARD V....Care Andrew & Palmer, 308 McPhee Bldg., Denver, Colo.
LER, CHARLES F........................Apartado 209, Torreon, Coahuila, Mexico.
ALL, S. A...1244 Humboldt Ave., Denver, Colo.

sons, Arthur R., Supt. of Mills, Tonopah Mining Co. of Nevada, Tonopah, Nev. '06.

sow, FREDK. M., Tampa Mine.............................Bingham Canyon, Utah.

TERSON, GEORGE H., Golden Wave Mining Co., 215 Colorado Bldg., Denver, Colo.

RSON, FRED S.........................20th floor, 25 Broad Street, New York, N. Y.

RSON, WILLIAM R., Engr...Goldyke, Nev.

LLIPS, WILLIAM B., Care Wm. B. Phillips & Co., 1917½ First Ave., Birmingham, Ala.

RCE, TALBOT E..............................Care Semet-Solvay Co., Syracuse, N. Y.

ER, JOHN W. H., Care E. B. Masadam, 31 Bartolome Mitre, Buenos Ayres, Argentine Republic, South America.

TT, EDWIN H., Western Mgr., Lanyon Zinc Co., 434 Cooper Bldg., Denver, Colo.

t, Frederick J., Elec. Engr.................625 Cornell Bldg., Scranton, Pa. '06.

EROY, HORACE G., Min. Engr., King of Arizona Co..................Kofa, Ariz.

EROY, WILLIAM E., Supt. Ocampo Mines, Greene Gold-Silver Co., Ocampo, Chihuahua, Mexico.

da, Julio, Min. Engr......Calle de Ojinaga, No. 21, Chihuahua, Mexico. '06.

CE, HARRY B..................................Apartado 1534, Mexico City, Mexico.

dy, Henry T., Elec. and Min. Engr., Puntarenas, Costa Rica, Cent. America. '06

NAM, DANA G.......................................1100 Santee St., Los Angeles, Cal.

IT, AUGUST...P. O. Box 828, New York, N. Y.

STON, WILLIAM C...................................368 Bush St., San Francisco, Cal.

DALL, HUNTLEY B. S.................................Apartado 71, Monterey, Mexico.

EN, FRED. R.......... ....Glen Cove, Long Island, N. Y.

EL, FERD. H..833 North 3d St., St. Louis, Mo.

D, GEORGE D., Iron Dyke Copper Co.................................Homestead, Oregon.

D, JOSEPH W.....................................116 South Front St. Memphis, Tenn.

nolds, Henry D. G., Southwest Smelting & Refining Co., Orogrande, New Mexico. '06.

E, JOHN F., Care S. A. A. Club.......................................Spokane, Wash.

HARDS, H. DE C., Genl. Mgr., Orleans Bar Gold Mining Co., Orleans, Humboldt County, Cal.

HARDS, JOHN V., Montezuma Development Co.........Box 175, Goldfield, Nev.

KETTS, L. D., Cananea Consolidated Copper Co........Cananea, Sonora, Mexico.

GE, H. MACKENZIE........Owbon Manor, Seaton Carew, Co. Durham, England.

G, AMBROSE E..................................536 West Mercury St., Butte, Montana.

ERA, LEOPOLDO..................Ia. de Revillagigedo No. 6, Mexico City, Mexico.

ertson, John H., Mine Mgr.......................P. O. Box 744, Joplin, Mo. '06.

ERTSON, PHILIP W. K...San Juan, Manuel, Mexico.

PPER, FRANCIS A...Georgetown, Colo.

SER, FREDERICK, Supt. Globe Plant, American Smelting & Refining Co, Denver, Colo.

E, LLOYD A., Care Lineberger & Rone................Torreon, Coahuila, Mexico.

E, HUGH...30 West 59th St., New York, N. Y.

S, GILBERT McM...Yosemite Club, Stockton, Cal.

BEL, MILTON L.........................San Andres de la Sierra, Durango, Mexico.

YON, WALTER C., Hotel Marie Antoinette, Broadway and 67th St., New York, N. Y.

sell, William C., Min. Engr. and Operator......................Tonopah, Nev. '06.

DER, THOMAS J..................................Apartado 1203, Mexico City, Mexico.

LIN, AXEL, Cons. Engr...Address wanted.

MAN, CHARLES W., Genl. Mgr. Mine & Smelter, Tintic Mining & Development Co., and Yampa Smelting Co., Salt Lake City, Utah.
OLZ, OSCAR F., Care Penna. Beach Creek & Eastern Coal Co., Cresson, Cambria County, Pa.
OBB, ROBERT....................................69 Fremont St., San Francisco, Cal.
TT, CHRISTIAN C. A., Care Alzamora, Talacio & Co., Barranquilla, Colombia, South America.
TT, HERBERT KILBURN..........46 Queen Victoria St., London, E. C., England.
F, EDWARD D., Care Lockwood National Bank..............San Antonio, Texas.
er, John C., Mine Supt., Paradise Mine.......P. O. Box 1, Paradise, Nev. '06.
PLEIGH, ROGERS W............730 North Cascade Ave., Colorado Springs, Colo.
RP, W. GOODENOUGH, The Surinam Gold Concessions, Ltd., Paramibo, Dutch Guiana, South America.
W, HOWARD I..Lewistown, Montana.
RA, EDWARD L................Naranjera, F. C. Coah., via Saltillo, Zac., Mexico.
RMAN, SCOTT H..622 Penn Ave., Denver, Colo.
PSON, H. R...1186 W. 30th St., Los Angeles, Cal.
es, Henry B., Mine Supt. and Cyanide Chem., 2337 South G St., Tacoma, Wash. '06.
AN, CHARLES E..2618 Etna St., Berkeley, Cal.
h, Frank D. G., Chem. and Assayer, Asst. Supt., Santo Domingo Silver Mining Co., Batopilas, Chili, South America. '06.
TH, J. BENNETT...280 Chestnut St., Kingston, Pa.
ERS, LAWRENCE D., Care Stone & Webster Corp.....84 State St., Boston, Mass.
AGUE, TIMOTHY W.....Broad Exchange Bldg., 88 Broad St., New York, N. Y.
ES, THOMAS W., Genl. Mgr. The Canadian Mines Syndicate, Ltd., Room 48, Citizens Bldg., Ottawa, Canada.
BER, LENA A., Care First National Bank...............................Pueblo, Colo.
AUSS, LESTER W., Care Julio W. East...............Lima, Peru, South America.
key, Leonard C., Min. Engr., Dulcinea Mine, near Copiapo, Chili, South America. '06.
ETSER, ARTHUR L.........................219 Warren St., Roxbury, Boston, Mass.
MAGE, ARCHIBALD A., Care Pittsburg Salt Lake Oil Co., Chamber of Commerce Bldg., Los Angeles, Cal.
HOW, WALTER, Care Rauntree & Diemond..........241 Park St., Portland, Ore.
NY, EMIL B, Mgr. Northern Iron Co................................Standish, N. Y.
RY, LAWRENCE M.................................1 East 39th St., New York, N. Y.
CHER, WILLIAM A.............................The Knutsford, Salt Lake City, Utah.
MAE, W. F. A., Min. Engr., Care Pearse, Kingston & Browne, Worcester House, Walbrook, London, E. C., England.
MAS, WILLIAM R., Tywarnhaile Synd., Ltd., No. 1 St. Helen's Place, London, E. C., England.
MLINSON, WILLIAM, Managing Director, Seaton Carew Iron Works, West Hartlepool, England.
RNE, WILLIAM E...East Auburn, Cal.
RNTON, EDWARD T., Min. Engr...Apartado 28, Velardena, Durango, Mexico.
OCKMORTON, HOWARD W.................Hotel Coronado, Coronado Beach, Cal.
RSTON, E. COPPEE.......................................703 Symes Bldg., Denver, Colo.
MONS, COLIN...Ameca, Jalisco, Mexico.
COMB, HAROLD ABBOT, Min. Engr., 43 Threadneedle St., London, E. C., England.
AT, F. H ....11448 Euclid Ave., Cleveland, Ohio.
NGOVE, SAMUEL R..Blanchard, Ariz.

J. W........Santa Fé Gold & Copper Mining Co., San Pedro, New Mexico.
, JOHN K........................Rooms 108–109, Golden Block, Reno, Nev.
W. E., Abangarez Gold Fields of Costa Rica,
Puntarenas, Costa Rica, Central America.
, HENRY R...........................Apartado 137, Aguascalientes, Mexico.
, ARTHUR L..................................1103 Broadway, Oakland, Cal.
, ETHEREDGE...........................819 W. Adams St., Los Angeles, Cal.
, RICHARD F...........................Mount Garnet, Queensland, Australia.
ER, RUEL C., Care E. V. Warriner......143 Cedar St., Springfield, Mass.
WEILER, FRED, Care Granite Bi-Metallic Cons. Mining Co.,
Philipsburg, Montana.
, CHARLES E...Address wanted.
, FRANK W., Vice-Prest., Pacific Coast Construction Co.,
112 Sherlock Bldg., Portland, Oregon.
, ROLLA B..............................18 Gramercy Park, New York, N. Y.
WILLIAM L., Min. Engr., Chem. and Assayer,
146 W. 28th St., Los Angeles, Cal.
PERCIVAL B.......................Casilla 16, Oruro, Bolivia, South America.
, ERASTUS H..................................Guanacevi, Durango, Mexico.
h, Irving H., Engr.................Matehuala, San Luis Potosi, Mexico. '06
, G. W.......................................Hotel Manitou, Salt Lake City, Utah.
ER, DE BERNIERE.................Juragua Iron Co., Santiago de Cuba, Cuba.
ER, WILLIAM L., Mgr., Oklahoma Portland Cement Co.,
Ada, Indian Territory.
JEFFRIES...Providencia-San Carlos Mining Co., Ocotlan, Oaxaca, Mexico.
LD, HUBERT E., Sandstone Development Gold Mining Co.,
Black Range, Western Australia.
, L. WEBSTER..Box 146, Ely, Nev.
EDWIN L., Care University Club..... ....Denver, Colo.
MS, EDWARD H., Care Perry Iron Co.................................Erie, Pa.
, *J. Miller, Jr.*, Asst. Supt., Cia Metalurgica Mexicana,
Sierra Mojada, Coahuila, Mexico. '06
MS, LEWIS.........................1938 Harvard Boulevard, Los Angeles, Cal.
MS, LUKE......................................"Claremont," Moonah, Tasmania.
ALFRED B.............................23 Toronto St., Toronto, Ont., Canada.
L, HALLETT, Andreyevski Mine, Station Itat, Trans-Siberian Ry., Siberia.
MARK A., Care Bank of Tarapaca and Argentina,
Antofagasta, Chili, South America.
IDGE, TYLER R.......................511 Dooly Bldg., Salt Lake City, Utah.
, HERBERT B.....................Clinchfield Coal Co., Johnson City, Tenn.

PROCEEDINGS OF THE ANNUAL MEETING.

the Annual Business Meeting of the Institute, held Feb- 19, 1907, the following persons were elected:

Council.

sident of the Council, John Hays Hammond, New York, . *Vice-Presidents* (for two years), Samuel B. Christy, eley, Cal.; John A. Church, New York, N. Y.; Persifor er, Philadelphia, Pa. *Councilors* (for three years), B. F. enthal, Jr., Easton, Pa.; H. O. Hofman, Boston, Mass.; er Renton Ingalls, New York, N. Y. *Secretary of the cil* (for one year), Rossiter W. Raymond, New York, N.Y.

Directors.

(To serve three years.)

nes Gayley, Charles Kirchhoff and Frank Lyman, all of York, N. Y.

RETARY'S NOTE.—The complete list of all officers of the Institute will be on p. iv. of this number of the *Bulletin*. The following explanation, first pub- in *Bi-Monthly Bulletin*, No. 8, March, 1906, p. viii., is here repeated in order ll to old members, and convey to new ones, the relations of the two governing as determined by the Certificate of Incorporation of the Institute, and the ution and By-Laws adopted in accordance therewith.

body legally responsible for the business management is the Board of nine ors (three elected annually to serve three years), which elects its own officers. ody, for reasons of practical convenience, is composed of well-known mem- siding in New York City, and able to attend, without serious inconvenience ense, the necessary meetings of the Board. The officers of this Board are the officers of the Institute. But, apart from business management, the exercises no control over the election of members, or the professional and cal work of the Institute, except that its vote is required to elect honorary rs, upon the recommendation of the Council.

Council is a body constituted in all respects (except that it has no Treasurer) e Council existing before the incorporation of the Institute, in January, 1905, arged with all duties and powers, except those which the Board of Directors egally perform. It elects members, appoints the times and places of profes- meetings, and controls the publication and distribution of papers and volumes, Its members (President, Vice-Presidents and Councilors) are elected by the ers of the Institute, voting in person or by proxy, and after publication of the ations received; and it is intended to represent, as far as practicable, both the sional and the geographical distribution of the membership. Consequently,

whatever professional honor attaches to official position belongs to membership in the Co ncil, rather than in the legal Board of Directors. This remark implies no disparagement of the members of the latter body, every one of whom has served, or is now serving, as a member of the Council. But it is only fair to explain that their election and continued re-election as Directors is simply a matter of legal convenience.]

PROCEEDINGS OF THE BOARD OF DIRECTORS.

he following acts of the Directors are reported for the in-
nation of the members:

t a meeting held May 10, 1906, the Secretary reported the
h, on April 16, 1906, of Mr. H. W. B. Howard, Assistant
retary and Assistant Treasurer of the Institute; also that
direction of the Council he had sent a copy of the resolution
ressing the sympathy and regret of the Institute to the
ily of Mr. Howard.

t the same meeting the Secretary and the Treasurer reported
ectively their appointment of Dr. Joseph Struthers as Assist-
Secretary and Assistant Treasurer, to fill the vacancies
ted by the death of Mr. Howard, and the said appoint-
ts were confirmed.

t the same meeting, Mr. Robert A. Hadfield, Sheffield,
land, and Mr. John E. Stead, Middlesborough, England,
ng been recommended by unanimous vote of the Council,
e unanimously elected Honorary Members, in recognition
heir distinguished services to the arts and professions repre-
ed by the Institute.

t the same meeting the Secretary presented the case of
nbers of the Institute, Public Libraries, etc., located in San
ncisco and vicinity, and it was

oted: That the Secretary be authorized in his discretion,
n average of one-half the usual price, to replace to members
he Institute, such publications thereof as have been de-
yed by the late catastrophe in California, and, in his dis-
ion to replace by gift the complete sets of the *Transactions*
nerly kept in libraries open to free public use, and by the
e Mining Bureau of California and the California Miners'
ociation. And in any case of peculiar hardship or merit, the
retary is authorized, with the approval of the President and
Treasurer, and of the Library Committee, to make further
uction of prices to members who have lost their copies of
itute publications as aforesaid.

At the meeting held Nov. 6, 1906, By-Law XIV. was amended by changing the number thereof to XV., and substituting therein the words "two-thirds" instead of "three-fourths," the By-Law, as amended, reading in full:

XV. AMENDMENTS.

These By-Laws may at any time be altered or amended by a vote of two-thirds of the Board of Directors, or by the members, at a business meeting of the Institute, in the same manner provided for amendments of the Constitution in Article XII. thereof.

At the same meeting, a new By-Law was added, as follows:

XIV. PUBLICATIONS.

The publications of the Institute shall include a periodical called the *Bi-Monthly Bulletin* of the American Institute of Mining Engineers, which shall contain reports of proceedings, professional papers, notices, and other matters of interest to members. From the annual dues paid by each member or associate, five dollars shall be deducted and applied as a subscription to the *Bi-Monthly Bulletin* for the year covered by such payment.

At the same meeting, the action of the Council providing for the issue and the circulation of the *Bi-Monthly Bulletin* and the procurement and insertion of suitable advertisements therein, was approved.

At a meeting held Feb. 19, 1907, directly after the adjournment of the Annual Meeting of the Institute, the following officers were elected for the ensuing year: *President*, James Gayley; *Vice-President*, James Douglas; *Secretary*, R. W. Raymond; *Treasurer*, Frank Lyman.

FINANCIAL STATEMENT.

The following statement of receipts and disbursements from Jan. 1 to Dec. 31, 1906, is published by authority of the Board of Directors.

RECEIPTS.

nce from statement of January, 1906,		$6,818.96
al dues,	$36,324.36	
memberships,	3,440.00	
ation fees,	2,960.20	
ing of *Transactions*,	3,493.12	
of publications,	3,000.62	
rotypes,	42.00	
ellaneous receipts,	166.97	
rtising,	15.00	
		49,442.27
est on bonds and deposits,		1,196.45
bursement from Special Fund for installments paid to e United Engineering Society,		43,000.00
bursement from Library Fund for library additions r 1905 and 1906),		1,041.67
		$101,499.35

DISBURSEMENTS.

ing Vol. XXXVI. of the *Transactions*,	$3,769.48	
ing *Bi-Monthly Bulletin* and extra pamphlets,	5,850.23	
ing circulars and ballots,	230.25	
ing Vol. XXXVI. of the *Transactions*,	2,925.00	
ing miscellaneous volumes,	450.75	
ing of exchanges,	357.20	
aving and electrotyping,	1,098.05	
tary's department, including clerks, stenographers l expenses of editing and proof-reading,	8,664.66	
urer's department, including collection of dues, ship- g, etc.,	7,126.25	
rian and assistant,	1,340.00	
ge,	1,915.11	
onery,	766.07	
	2,500.00	
ess and freight charges,	1,212.67	
hone,	248.55	
grams, cables, carfares,	65.98	
e supplies and repairs,	145.62	
ge of *Transactions*,	187.98	
nding over-payments,	16.00	
ance premiums,	271.43	
ction charges,	35.47	
a clerical assistance,	132.50	
al stenographers and expense of meetings, etc.,	1,131.92	
ting,	125.00	
rtising expenses,	19.72	
e cleaning and sundry expenses,	135.75	
		$40,721.64
est, being proportion due for 1905 and 1906 on land rtgage loan to Andrew Carnegie on Engineering So- ty's property,		9,133.33
e equipment,		41.95

Library additions, ...	363.65
United Engineering Society, instalment payments under agreement, ...	50,000.00
Balance, ...	1,238.78
	$101,499.35

NEW YORK CITY, January 30, 1907.

We have examined the above statement, compared it with the books and vouchers and find same correct.

(Signed) BARROW, WADE, GUTHRIE & Co.,
Certified Public Accountants.

[SECRETARY'S NOTE.—The payment of $50,000 of the principal of the land mortgage loan will reduce the annual interest by $2,000. It is expected that further reductions of the principal will be made soon, from the special fund to be collected for that purpose. Of the $50,000 already paid, $43,000 has been reimbursed from that fund, and the remaining $7,000 will shortly be paid into the treasury of the Institute, upon the receipt by the Special Fund Committee of subscriptions already made.—R. W. R.]

PROCEEDINGS OF THE COUNCIL.

The following report is published for the information of the embers:

Meetings.

Two meetings for the reading and discussion of papers, etc., ve been held during the year 1906—namely, the Ninetieth eting, held February 21st to 24th at Bethlehem, Pa., and Ninety-first meeting, held July 24th to 27th in London, gland, in connection with the meeting of the Iron and Steel titute.

The proceedings of these meetings, including descriptions of entertainments and excursions connected therewith, have eady been published and distributed to the members of the titute; the Bethlehem meeting in *Bi-Monthly Bulletin*, No. May, 1906, pp. 497 to 508, and the London meeting in *Bi-nthly Bulletin*, No. 12, November, 1906, pp. 809 to 908. The ceedings of the London meeting were published separately l distributed among the many individuals and concerns ose cordial friendship and delightful hospitality contributed largely to the success of the visits in London and environs l the excursions in England, Scotland and Germany.

At the Bethlehem meeting, 37 papers and discussions were sented and the names of 198 members and guests were registed at the Institute headquarters; this number, however, does represent all who were present at the sessions and excurns. At the London meeting, 26 papers and discussions re presented, not including 5 of the papers and discussions d before the Iron and Steel Institute at the joint session h the American Institute of Mining Engineers, which, by a tual agreement between the Councils of the two Institutes, ve been selected to be republished in the *Bi-Monthly Bulletin* l *Transactions* of the Institute. The number of members l guests of the two Institutes registered at the London adquarters was 908, and of this number 131 were from nerica. This list does not include the names of all who

were present at the sessions or took part in the numerous excursions and visits around London. About 100 American members of our Institute joined the excursion through England and Scotland with members of the Iron and Steel Institute, and a like number were registered at Düsseldorf for the special excursion in Germany.

Publications.

Transactions.—Volume XXXVI. of the *Transactions*, an octavo of 1001 pages, comprising 59 papers and discussions presented during the year 1905, was issued and distributed in June, a gain in time of appearance in the year of 1 month over Volume XXXV., 5 months over XXXIV. and 10 months over XXXIII. For this gain in time of publication due credit should be given to Dr. Joseph Struthers, the Editor and Assistant Secretary of the Institute.

The material (excepting the index and one or two papers, the final proofs of which have not yet been returned by the authors), for Volume XXXVII., comprising in all about 1050 pages, is now in the hands of the printer, and unless delayed by unfortuitous circumstances not now apparent, the volume should be printed and distributed to members and exchanges in June, 1907.

Index.—The compilation of the collective index of the *Transactions*, Volumes I. to XXXV., inclusive, has been carried on during the year under the charge of our efficient librarian, Miss L. E. Howard, and the manuscript is now nearly completed. Unfortunately for the early appearance of this index, the many additional duties incident to moving the entire office and library of the Institute from 99 John St. to our new home in the Engineering Society Building have delayed progress on this special work, but it is hoped that the publication will be ready for distribution during the coming summer. The magnitude of this Index, involving the collection, sorting, classification and completion of many thousand titles, names and cross-references, can only be fully appreciated by those who have done work of similar character. The Index when completed will form a book about as large as the average volume of the *Transactions*.

Bi-Monthly Bulletin.—Six numbers of the *Bi-Monthly Bulletin* (Nos. 7 to 12), containing the technical papers of the Institute and announcements of general interest to the members

the Institute, such as Library accessions and requirements, s of new members and associates, deaths of old members, gress on the United Engineering Society Building, etc., re been published and distributed promptly throughout the r 1906. The number of pages occupied by technical papers ounts to 1164, to which is to be added 140 pages of annoncements, making a total of 1204 pages of printed matter.

The management of the *Bi-Monthly Bulletin* and the forthning Volume XXXVII. of the *Transactions* continues in rge of Dr. Joseph Struthers, the Assistant Secretary and itor, to whose industry and zeal the success of these publicans is largely due.

Membership.

Changes in membership have taken place during the year as ows:—3 honorary members (previously on the regular list members), 283 members and 13 associates have been cted; 3 members have been elected honorary members, and associates have become members; the deaths of 40 mems and 2 associates have been reported; 29 members and 3 ociates have resigned; and 56 members and 6 associates e been dropped from the roll by reason of non-payment of s, loss of correct address, etc.* These changes are shown he accompanying table.

The total membership on January 1, 1907, was 4,048, as comed with 3,884 on January 1, 1906—a net gain for the year 164 members.

Membership of the American Institute of Mining Engineers, January 1, 1907.

	Honorary Members.	Members.	Associate Members.	Totals.
nbership Dec. 31, 1905	8	3,682	194	3,884
ns: By Election	....	283	13	296
Change of Status	3	17	....	20
Reinstatement	....	3	....	3
Re-election	....	1	....	1
ses: By Resignation	....	29	3	32
Dropping	....	56	6	62
Change of Status	....	3	17	20
Death	....	40	2	42
al gains	3	304	13	320
al losses	....	128	28	156
nbership Dec. 31, 1906	11	3,858	179	4,048

Many of these, no doubt, will be reinstated, as has been the case in former rs.

The list of deaths reported during the year 1906, comprises the following names, the figures in parentheses indicating the year in which the persons named were elected to membership:

Members and Associates.—Arthur Vaughn Abbott (1882), William Anderson Akers (1889), R. Scott Allen (1905), George H. Arlett (1900), Thomas Septimus Austin (1883), Thomas T. Baker (1887), William Tittley Batchelor (1902), Charles Lothian Bell (1897), Edgar Vallentine Bensusan (1892), Ernst Elmer Breisch (1896), Horace F. Brown (1895), James A. Burden (1876), Alexander B. Coxe (1880), George A. Crocker (1879), John Herbert Fraser (1904), Robert Gibson (1892), R. G. Hart (1900), Alexander W. Jolly (1899), George L. Keener (1900), John G. Lanning (1893), Gustavus W. Lehmann (1891), Nicholas Lennig (1882), William H. Long (1882), Frank C. Mandell (1905), Edmund H. Miller (1895), John Fossbrook Morris (1903), F. J. Odling (1893), William Painter (1893), Stanley Pearce (1896), Herman Poole (1900), Ricardo G. Ramos (1898), Arthur F. Rising (1904), George H. Robinson (1886), Albert W. Sayles (1905), Richard J. Seddon (1888), James C. Simpson (1887), Francis Lewis Sperry (1889), John Stanton (1877), Edward G. Stoiber (1877), Samuel Thomas (1871), Abel Hyde Toll (1900), John Price Wetherill (1896).

Of these, Alexander B. Coxe, Thomas S. Austin and Samuel Thomas have been made the subjects of special Biographical Notices. That of Alexander B. Coxe was printed in *Bi-Monthly Bulletin*, No. 11, September, 1906, pp. 701 to 705, and those of Messrs. Austin and Thomas will be presented in later issues of this publication.

TANDARDIZATION COMMITTEES OF THE INSTITUTION OF MINING AND METALLURGY.

the request of Mr. C. McDermid, Secretary of the Insti-
n of Mining and Metallurgy, Salisbury House, London,
, England, the following reports of standardization com-
es are here republished. Mr. McDermid invites members
e American Institute of Mining Engineers to write him
xpress their opinion of the various proposals made by the
nittees.

OF THE REPORT OF THE WEIGHTS AND MEASURES STAND-
RDIZATION COMMITTEE OF THE INSTITUTION OF MINING
ND METALLURGY, as adopted by the Central Standardiza-
ion Committee, Dec. 20, 1906, and submitted to the
Council, Jan. 16, 1907.

**OTE.—Before finally adopting the recommendations of
ommittee, the Council will be glad to consider any sug-
d alterations, which should be received by the Secretary
ater than June 30, 1907.**

Chairman and Members of the
CENTRAL STANDARDIZATION COMMITTEE.

EMEN,

Weights and Measures Standardization Committee submit the following rec-
dations for adoption by the Central Committee:—

hat the word "ton" shall represent a weight of 2,000 lb. avoirdupois
.6 oz. troy); that the use of the terms "cwt." and "qrs." be abandoned,
t fractions of a ton be expressed either in pounds or in decimals of a ton.

hat the "miner's inch" be understood to mean a flow of 1.5 cu. ft. of water
nute.

hat the word "gallon" be understoood to mean the Imperial gallon of

hat all temperatures be expressed in degrees Centigrade.

hat gold and silver returns be expressed in terms of fine gold and silver, and
"bullion."

hat gold contents of ores, etc., be expressed in money values as well as in
; and that in this connection the standard value be taken at 85 shillings, or
U. S. currency, per troy ounce fine gold.

also suggest that the following questions be appended to any Memorandum

that may be issued to the Members of the Institution embodying the above definitions:—

(*a*) Do you consider the general adoption of the Metric system of weights and measures to be feasible in mining and metallurgical work, or would this in your opinion lead to undue dislocation?

(*b*) Have you any suggestion to make as to weights and measures other than those already dealt with, which require exact definition?

The question of the adoption of Metric standards has engaged the attention of the Committee, as the present movement in that direction in other branches of industry rendered it, in their opinion, inadvisable to ignore it entirely.

The feeling of the Committee, however, is that, while the question should be brought to the attention of the members, it would at present be quite inexpedient to advocate the general adoption of the Metric system in mining and metallurgical work.

On the other hand, an attempt to decimalize existing weights and measures is considered to be a step in the right direction, and as tending to bring about a desirable simplification.

I am, Gentlemen,
Yours obediently,
(Signed) H. LIVINGSTONE SULMAN,
Chairman of Sectional Committee "A"—
Weights and Measures.

December 13, 1906.

COPY OF THE REPORT OF THE MESH STANDARDIZATION COMMITTEE OF THE INSTITUTION OF MINING AND METALLURGY, as adopted by the Central Standardization Committee, Dec. 20, 1906, and submitted to the Council, Jan. 16, 1907.

NOTE.—Before finally adopting the recommendations of the Committee, the Council will be glad to consider any suggested alterations, which should be received by the Secretary not later than June 30, 1907.

To the Chairman and Members of the
CENTRAL STANDARDIZATION COMMITTEE.

GENTLEMEN,

I have pleasure in submitting the Report of Sectional Committee "C"—Mesh, on the questions referred to them for consideration.

The Committee unanimously recommend the adoption of the following as "The I.M.M. Standard Laboratory-Screens":—

or Apertures inear Inch.	l iameter of Wire.	Aperture.	Screening-Area.
	Inch.	Inch.	Per Cent.
5	0.1	0.1	25.00
8	0.063	0.062	24.60
10	0.05	0.05	25.00
12	0.0417	0.0416	24.92
16	0.0313	0.0312	24.92
20	0.025	0.025	25.00
25	0.02	0.02	25.00
30	0.0167	0.0166	24.80
35	0.0143	0.0142	24.70
40	0.0125	0.0125	25.00
50	0.01	0.01	25.00
60	0.0083	0.0083	24.80
70	0.0071	0.0071	24.70
80	0.0063	0.0062	24.60
100	0.005	0.005	25.00
150	0.0033	0.0033	24.50
200	0.0025	0.0025	25.00

.—Owing to difficulties in wire-drawing and in the weaving of wire cloth, accuracy to the fourth place of decimals of an inch is unattainable with ty of 25 per cent. of screening-area; but the above table is so near to theo- erfection, and the unavoidable irregularities of screening-tests themselves ide that any inaccuracies in the table would be absolutely immaterial in It is not possible to weave the 200-mesh screen except in what is known led" or double wire.

dvantages of the series are:—

at a definite ratio and a corresponding arithmetical progression of both and mesh is secured.

at by adopting a screening-area of 25 per cent., the wires are absolutely " in position, thereby preventing shifting and consequent irregularity in of aperture.

at the ratio between wire and aperture in all meshes being constant, the taper of the hole is also constant.

ommittee append a Memorandum explaining in some detail the grounds ments upon which their recommendations are based, and they desire to add e recommendations are the result of the most careful consideration of the d suggestions of users of screens in all parts of the world, and of the views h and American manufacturers

gards the more exact definition of the word "slimes," the Committee sug-

at material coarser than 150 mesh be described as "Sand," coarse or fine.

at material passing 150 mesh but settling in seconds in a inch of water be described as "Meal," and—

at material settling more slowly in water be described as "Slimes."

(Signed) WALTER McDERMOTT,

Chairman of

ber 17, 1906. *Sectional Committee "C"—Mesh.*

.—Orders for "The I.M.M. Standard Laboratory-Screens" can be placed tain makers, whose names will be supplied by the Secretary of the Insti-

SECTION II.

TECHNICAL PAPERS AND DISCUSSIONS.

[The American Institute of Mining Engineers does not assume responsibility for any statement of fact or opinion advanced in its papers or discussions.]

A detailed list of the papers contained in this section is given in the Table of Contents, pages i and ii.

Comments or criticisms upon all papers given in this section, whether private corrections of typographical or other errors or communications for publication as "Discussions," or independent papers on the same or a related subject, are earnestly invited.

ERRATA.

Corrections to *Bi-Monthly Bulletin*, No. 13, January, 1907.

Page.

i, last line. For "H. O. Hofman" read "H. O. Hofman, W. S. Caypless and E. E. Harrington."

ii, first line. For "H. O. Hofman" read "H. O. Hofman, R. P. Reynolds and A. E. Wells."

10, Table II., line 3. Under "Cu," for "58.25" read "38.25."

114, line 17. For "Thomas Price-Williams" read "R. Price-Williams."

124, last line. For "owing" read "owning."

144, line 4. For "A. H. Winchell" read "H. V. Winchell."

CT TO REVISION.

RANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Piping and Segregation in Steel Ingots.

PRELIMINARY PAPER.

BY HENRY M. HOWE, LL.D., NEW YORK, N. Y.*

(London Meeting, July, 1906.)

1. *Introduction.*—The first part of this paper[a] treats of the es and the restraining of piping in steel ingots; the second[b] ders the causes and the restraining of segregation; and hird[c] proposes certain precautions in engineering specifica- concerning these two defects. Into their causes I have ed carefully, with the purpose of arriving at rational meth- f restraining them, and at efficient ways of detecting and uring the harm which they cause, so as to benefit the pub- reducing this harm at once effectively and with the least nse to the manufacturer, and therefore in the end with the expense to the consumer.

Part I., I infer that the pipe is chiefly due to what I call irtual expansion of the outer walls of the ingot in the early of the freezing.[d] I find that the upper and smooth-faced of the pipe probably forms while the interior is still mol- but that the lower, steep, and crystal-faced part probably s in metal which is already firm. Of the five causes which co-operate to limit the depth of the pipe, I find that —blow-holes, sagging, and the progress of freezing from v upwards—are usually effective. I find that the pipe be lessened by casting (1) in wide ingots[e]; (2) in sand s,[f] especially if these are pre-heated (this is rarely expe-); (3) at the top[g] instead of at the bottom; (4) slowly[h]; nd with the large end up[i]; (6) by the use of a sinking- or other means of retarding the cooling of the top[j]; (7) ermitting blow-holes to form[k]; and (8) by liquid compres- [l] Most of these I consider in some detail, and in particular ell on the advantages of casting with the large end up, and pose certain administrative arrangements to permit this.

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rofessor of Metallurgy, Columbia University, New York, N. Y.

. 171. [b] P. 241. [c] P. 265. [d] P. 183. [e] P. 222. [f] P. 223.

. 225. [h] P. 226. [i] P. 226. [j] P. 232. [k] P. 236. [l] P. 236.

In Part II., p. 241, I find that, although the reasons why (1) casting in wide ingots and (2) in sand- or clay-lined molds shorten the pipe do not apply to show that they should raise the segregate, yet the position of the segregate should be raised by the six other means by which the pipe is shortened, viz.: by casting (3) at the top, (4) slowly, and (5) with the large end up; (6) by the use of a sinking-head or other means of retarding the cooling of the top; (7) by allowing blow-holes to form; and (8) by liquid compression.

I next consider in § 53, p. 243, the means proposed for lessening the degree of segregation, as distinguished from raising the position of the segregate, viz.:

(9) Quieting the steel by adding aluminum;

(10) Casting in small instead of in large ingots; and hastening the solidification, not only by casting in small ingots, but also

(11) By casting at a low temperature;

(12) By casting in thick-walled iron molds (*i.e.*, those of high thermal conductivity); and

(13) By casting slowly.

Pending the completion of further experiments and an analysis of the data, I point out that (9) quieting the steel has materially lessened segregation in certain cases, and I hold that (10) segregation is probably much less in small than in large ingots, but that rapid cooling has certain effects which tend to lessen segregation and others which tend to increase it, so that its net effect should be expected to differ both in importance and in sign from case to case; and I find that the evidence agrees with this inference.[1]

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[1] In the original draft of this paper, prepared for the London meeting under more pressure than favors proper deliberation, I adopted, with some qualifications, the current opinions that slow cooling increases segregation and rapid cooling opposes it, and that segregation is much greater in large than in small ingots. Prolonged further study of the conditions and evidence, while it goes to show that my contention as regards ingot-size was right, yet shows that in sudden cooling two sets of causes are at work, of which one tends to lessen and the other to increase segregation. But the influence of ingot-size and that of rate of cooling are so important that I have decided to seek further and more conclusive evidence by means of direct experiments, which are now in hand. Their results, together with a thorough analysis of the present data, I hope to present in a later paper. In 1894 I expressed my belief "that there are many other cases in which hastening solidification favors segregation." (*Journal of the Iron and Steel Institute*, vol. xlvi. (1894, No. II.) p. 115.)

[consider at great length in § 60 the effectiveness of the dif-ent methods of fluid compression, concluding that Whit-rth's system should be the least effective, S. T. Williams's most effective, and the systems of Harmet and Illingworth ermediate in effectiveness in raising the segregate.

n Part III., I consider briefly the relations of maker and er, the reasons which lead to secrecy in manufacture, and ecially the imperfect protection which patents can give to ny metallurgical inventions. I then lay stress on inspection he rolls and shears, and especially on axial drilling of the ets or other products.

'he different means of restraining piping and segregation ch have here been studied are then recapitulated,[m] and the er ends with an explanation of why it is that, of these va-s means, only (3) top casting can well be insisted on in the ority of cases; and why in certain special important cases buyer may consider carefully whether he may not reason-insist that casting shall be done (5) with the large end up, with a sinking-head or its equivalent, and (10) in ingots not ger than 8 in. square.

I. Piping.

2. *When does the pipe form?* The pipe in a cold ingot, *E*, . 1, is a hollow space, filled with gas, and shaped like an erted bell. This shape goes to show that the pipe forms ing solidification, somewhat as sketched in Fig. 1, although shall see in §§ 32 and 33 that, when its lower end stretches n with steep, nearly parallel, and rough sides, this lower part robably opened as a chasm in the already solid metal. Let now follow the general course of the formation of the pipe. Vhen the very outer crust of the ingot solidifies, its form size are those of the molten metal within it; it fits over molten metal as a bottle does over its contents of water, or tight glove fits over the hand. As freezing proceeds, and solid walls of the ingot grow thicker by the deposition of cessive layers of solid steel out of the molten interior, layer n layer, a moment arrives when this molten interior no longer ices to fill completely the solid inclosing crust, somewhat if during the progress of emaciation from some protracted ess, I should retain the glove which once fitted my hand

[m] P. 272.

but now creases over it, or as if water were to leak out through a crack in the bottom of a once well-filled bottle. As the water leaks out more and more, the tide in the bottle may be said to fall gradually. As the ebbing tide leaves on the beach a deposit, of which each line represents the water-mark at some given instant in that ebb, so if the water is soiled it leaves on

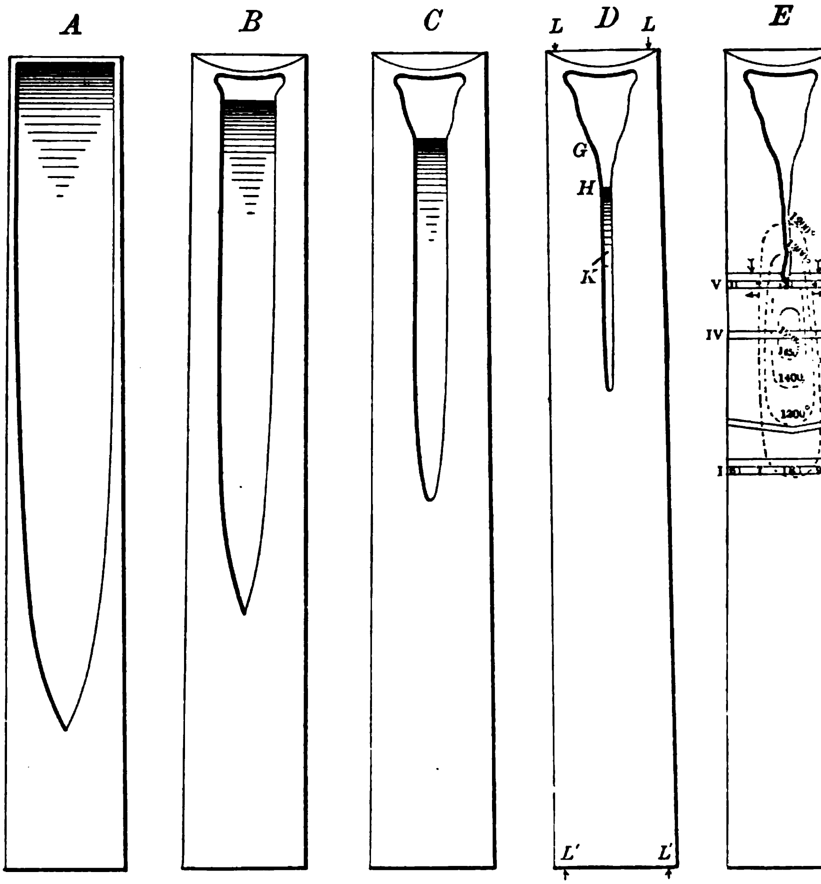


FIG. 1.—SUPPOSED GENESIS OF A PIPE IN A SOLIDIFYING STEEL INGOT.

the sides of our bottle such a succession of lines, representing the level of the water's surface at successive stages during this *quasi* ebb; and thus a succession of imaginary horizontal lines around the surface of the pipe represents the upper surface of the molten steel at successive stages during the ebb of this land-bound, indeed subterranean, deep lake or covered well, the progressively sinking mass of molten steel.

. 2 shows on a larger scale the condition of affairs at a stage during the formation of the pipe, when the tide ready ebbed from *ef* to *bg*, leaving the space *efbg* vacant. the surface *bg* the lake of molten steel penetrates deep into the ingot, with the outer walls of which its sides are ly parallel: although they probably draw together in the part somewhat as sketched in Fig. 1, first because the steel lower part is poured into the mold earlier than that in pper part, so that at any given instant cooling and solidin have advanced further in the lower than in the upper and second, because the cooling of the lower part is hastby its necessarily firm contact with the thick and initially tool which forms the bottom of the mold.

diameter of the pipe at any given level, in Fig. 2, represents approximately the of the upper surface of the subterramolten lake at the moment when this was same level.[2] The diameter of the pipe omewhat lower level, *b*, gives the width is lake when the tide had fallen to *b*; ickness *c* represents the thickness to the walls had frozen when the tide was el *a*, and the thickness *d* represents that walls when the tide had fallen to *b*; he excess of *d* over *c* represents the nt of thickening of the walls which took place while the as sinking from *a* to *b*.

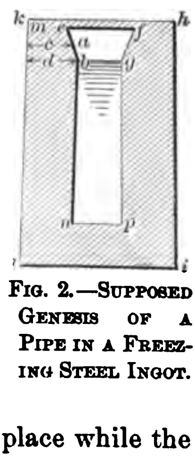


FIG. 2.—SUPPOSED GENESIS OF A PIPE IN A FREEZING STEEL INGOT.

us the thickness of the ingot-walls, *em*, at the very top of pe is the thickness of those walls when the molten metal eased to fill completely the solid shell, when the first incy of the pipe formed, when the tide first began to fall; he fact that the pipe decreases in width from top to bothows that while it was forming—*i.e.*, while the tide was ally falling—the ingot-walls were gradually thickening; short, that the pipe forms during freezing, while the steel sing progressively from the molten to the solid state. might seem clear enough beforehand; but I want to leave

is width is, of course, modified by the contraction of the metal during the ent cooling; but throughout this section I ignore these later modifica- size for simplicity of presentation.

no doubt in your mind that it is during this freezing of the metal, during the successive deposition of solid layer after layer from out of the molten lake against its shores, the already solid walls, that the pipe actually forms.

The sharp pointing of the lower end of the pipe indicates that it continued to open at least up to the time when the last remnant of a puddle there had frozen; for otherwise this lower end would be level, or at least meniscus shaped, like the surface of water frozen at the bottom of a conical mold.

The shape and position of the pipe in the zinc ingot, shown in Fig. 15, III., p. 207, leave hardly a doubt that here the pipe has formed in the way just described. When we compare this pipe with those in ingots I. and II. of this same figure, we readily admit that these, too, have probably formed in this same way, and the more readily after we have seen in § 42 that casting these with their large ends down ought to have just this effect of very greatly lengthening the pipe.

From this admission to the further one that this is the way in which the usual subterranean pipe is formed in steel ingots, such as are shown in Figs. 1, 2, 12, 13, 20, 21, and 22, is an easy step, made easier by the fact that even in steel the pipe is open at the top and in general like that of Figs. 15, I. and II., when the conditions favor this form, as will be explained in § 38.

§ 3. *Why does the pipe form?* Our common answer has been substantially this: "The dimensions of the shell of the ingot at the moment when it solidifies are determined by the volume of the molten interior. The contraction of this interior in freezing exceeds the contraction of the shell, progressively more and more, so that the molten interior falls progressively further and further short of filling completely its inclosing shell; and consequently the empty space or pipe in the cold ingot represents this shortage."

§ 4. *Metals which expand in solidifying also contain a pipe.* The foregoing answer, though it contains much truth, not only is inaccurate in form, but wholly fails to explain either why gray cast-iron, which certainly expands in solidifying, also forms a pipe,[3] or why the pipe is so large in steel ingots.

[3] In casting large cast-iron rolls, which stand with their axis vertical when casting, unless they are properly fed to anticipate this piping tendency the pipe itself may stretch down as much as a foot, and there may be a spongy region

Fig. 1, *E*, shows an ingot in my collection with a pipe hich seems very much too great to be due simply to the exess of contraction of the molten interior over that of the outer nell. When the very outer shell is freezing, the molten inrior must be very near the freezing-point; there cannot be ny large difference of temperature between them. That the ontraction of the molten interior in cooling slowly through nese few degrees to the freezing-point should exceed the simulneous contraction of the now fast-cooling shell by the amount hich this large pipe represents, seems to me simply inconeivable.

Because this explanation fails to explain either the presence a pipe in gray cast-iron, or why the pipe is at times so large steel ingots, and, indeed, in ingots in general, there must be nother cause for the pipe, and this cause I will explain in § 6.

§ 5. *Does steel expand or contract in solidifying?* Does it exand as water[4] and gray cast-iron do, or does it behave like the reat majority of substances and contract progressively in coolg towards, at, and below the freezing-point, until the critical mperatures (Ar_3, etc.) of the solid state are reached?

When I began this study I certainly believed that iron expanded, ecause I was so familiar with the floating of the puddled bars hich I used to charge in the acid open-hearth furnace. In my wn practice these puddled bars were pre-heated, and they most rtainly floated about in the bath, and as I remember them they

retching down another foot below the bottom of the pipe. (Richard Moldenke, ı.D., private communication, May 15, 1906.) Naturally, there is less piping gray than in white cast-iron, because the separation of graphite in the former uses an expansion which tends to efface the pipe.

[4] Those who see in evolution not aimless chance but benevolent design, a presigning of the world to fit a man who, after endless æons, would inhabit it, ay point to the floating of ice as a benevolent way, first of preventing ponds om freezing solid to the bottom, and therefore remaining ice-cold until midmmer, and second, of giving man a bridge across stream and lake at a season nen his body could not endure swimming, wading, or even fording. They can int to the sudden expansion in freezing of the most important of all castingetals, gray cast-iron, as a benevolent means of enabling man to fill his molds arply. They can point further to the fact, if, as I believe, it is a fact, that man's eye n read temperature by the color of red-hot steel incomparably more accurately that range in which he needs great accuracy—viz., in the range in which steel quires the hardening power—than in any other range of temperature. Here e eye seems to have been pre-fitted to a special purpose, for which it was not be used until geological ages after that pre-fitting.

floated evenly, like so many boards in water. On consulting others of long experience with the open-hearth process I find that most of them are positive about this floating; indeed, the reason why I took up this study was that I could not answer on the spot the question put to me by an eminent open-hearth steel-maker, "How comes it that, though solid steel is certainly lighter than molten steel, as is shown by its floating, yet in freezing a pipe forms within it?"

Further study has led me to doubt, for four reasons, whether solid steel is really lighter than the same steel when molten: (1) a very competent observer with admirable opportunities informs me that, in his basic open-hearth practice, solid scrap-steel never floats on the molten bath except under unusual conditions; (2) when I had pieces of hammered steel about 2 in. square and 8 in. long immersed in the molten steel in the casting-ladle after the slag had been pushed aside, they invariably sank out of sight and did not reappear, even in a case in which the solid steel had been strongly pre-heated; (3) Moissan's observation that, though buttons of cast-iron nearly saturated with carbon, in freezing eject molten matter through their upper crust, yet like buttons of steel containing less than 1 per cent. of carbon never do, led him to infer that, though such cast-iron expands in solidifying, steel contracts;[5] (4) the fact that the segregate in steel ingots is invariably much above the middle of the length of the ingot, goes to show that molten steel continues contracting as it nears the freezing-point, as explained in § 46, p. 234.

If we were forced to make a definite assumption, then, in view of the fact that there is no conclusive proof that steel expands, and that the circumstantial evidence is inconclusive, pointing about as strongly in one direction as in the other, our reasonable course would be to assume that steel follows the general course of nature and contracts continuously past the freezing-point. But because no final assumption is necessary, we may leave the question open and assume provisionally that the contraction is continuous before, during and after freezing, and see why it is under this assumption that the pipe forms. Next, passing from the simple to the complex, let us see how it may come about that a pipe yet

[5] *Comptes rendus*, vol. cxl., pp. 185 to 192 (1905). See § 18, p. 197, of the present paper.

rm in a substance which, like gray cast-iron and water, ly expands near the freezing-point; and if it should e proved that steel expands in freezing, the explanation or the piping of ice and gray cast-iron would suffice to the piping in steel.

the change of volume of steel in freezing, whether it is an ion or a contraction, is probably small, not comparable e expansion of ice and gray cast-iron, and wholly incom- to explain the often large volume of a pipe.

assing, let me explain why this evidence that steel con- n freezing seems to me inconclusive.

scrap-steel is not seen to float in certain basic open-hearth e is inconclusive for several reasons. If it projected but above the surface of the molten bath, this projecting well be so masked by the overlying thick layer of slag as unnoticed. Again, if the scrap does sink, this may be e the bath into which it is charged is so much richer in as to be materially lighter than the scrap-steel itself would olten. The question is not whether low-carbon steel ill float on molten high-carbon steel or on molten cast- ut whether it will float on molten steel of its own com- n. Finally, even if steel does expand in solidifying, yet eel scrap might still sink in molten steel of its own com- n, for even gray cast-iron when cold sinks in like cast-iron olten, and only after it has grown hot does it again rise surface. In case of steel scrap charged cold, it might not ole be heated near enough to the melting-point to become nough to float, until so much of it had melted away that le which remained would project so little as to be masked overlying slag.

sinking of solid steel bars in the casting-ladle in my periments is not conclusive, because the molten steel ry far above its melting-point and the scrap was very far ts melting-point.

san's results are inconclusive for reasons which we will in § 18 after further study of this general question, e high position of the segregate is inconclusive for rea- plained in § 46, p. 234.

he other hand, the very common observation, my own d, that pre-heated solid scrap-steel floats in the acid

open-hearth furnace is not strictly conclusive, because this scrap is charged through the molten slag, and enough slag may adhere to it to buoy it up. Again, gas-bubbles may buoy it up, quite as the bubbles in a glass of champagne will buoy up crumbs of bread dropped in. I attach little weight to this explanation, because the buoying action of these bubbles ought to be very irregular, making the scrap bob up and down, with a strong evolution of gas around it, whereas my observation has been that the scrap floats quietly if the bath itself is quiet.

Again, the pipe in steel ingots (except in very narrow ones, as explained in § 38), instead of being open as it is in the zinc ingots of Fig. 15, is covered with a level crust, often of considerable thickness. From this we might at first infer that the metal expands in freezing ; but, as I will explain in § 14, such an inference would be unjustified.

§ 6. *Another explanation offered.* Carrying our analysis further, let us divide the freezing-period into two parts, one which precedes and one which accompanies the formation of the pipe, or into the "pipeless" and the "piping" periods; and let us divide the shell of the ingot into two imaginary concentric layers, an outer very thin one, as thin as you please, and an inner one which comprises all the rest of the metal which solidifies during the ante-piping period, or which has solidified up to any special time under consideration. These two parts we may, for brevity, call the outer walls and the inner walls. Note these meanings.

This done, my explanation is that during the pipeless period the outer walls are virtually and permanently much expanded by the resistance which the inner walls, and the molten metal too in case the top of the ingot is firmly frozen over, oppose to their normal contraction; and that during the piping period the contraction of the inner walls, welded as they are to the outer walls thus virtually expanded, causes them to draw outwards, leaving an empty space, the pipe.

It is not only that the volume of the molten interior, at the moment of solidification of the outer crust, determines the initial dimensions of this crust, but more especially that the lagging cooling of the inner walls determines afterwards the virtual expansion of this crust; and it is rather the contraction of the inner walls after freezing, than the contraction of the

en interior before and during freezing, that later makes nterior fall short of filling the outer shell, and thus causes ipe.

t us now go on to consider the pipeless and the piping pe- separately.

7. *Virtual expansion of the outer walls in the pipeless period.* n freezing first begins, the very outermost layers—that is to the outer walls—cool much faster than the layers within —that is to say, the inner walls—because the former are in ediate contact with the cold walls of the mold. Cooling r, they tend to contract faster; but this tendency to excess ntraction is resisted by the inner walls. The outer walls ike a tire shrunk upon a wheel which itself is contracting slowly than that tire. At the very first this resistance of softer and weaker inner walls may have little effect; but ey grow thicker and thicker, and as their outer part be- s firmer and firmer, so do they resist the more effectually ndeavor of the outer walls to contract faster than the inner In so far as this resistance is effectual, it virtually ex- s the outer walls, in the sense that it prevents them from racting at the normal rate which they would have followed for this resistance, so that at each temperature they are r than they would have been had their contraction been sisted. By as much as they are thus larger, by so much hey virtually expanded.

3. *Virtual expansion persists.* By as much as the virtual nsion of the outer walls, which has taken place up to the of reaching any given temperature in the cooling, has ex- ed the then existing elastic limit, by so much will it tend rsist during the remainder of the cooling. If, for instance, aching a temperature of 1,000° C. the virtual expansion such that the ingot was 1 in. wider than it would have if the contraction of the outer walls from their initial had been unresisted, and if by some device the inner could be bodily removed from within the outer walls, latter, resuming their natural rate of contraction, would ract from their present size as a datum size; and at the of the cooling they would remain 1 in. wider than they d have been had their contraction been unresisted from ery beginning.

Of course, the virtual expansion which has taken place up to any given moment may be augmented later by the continued working of like causes; or it may be lessened by centripetal stress either from without (such as atmospheric pressure) or from within. For our present purpose it suffices that any virtual expansion tends to persist.

§ 9. *Later the inner walls contract faster than the outer walls.* Although at the beginning of the freezing the outer walls, because of their contact with the initially cold walls of the mold, cool faster than the inner walls, later a time must come when this is reversed and the inner walls cool faster than the outer ones, as the least reflection makes clear. Suppose, for instance, that at some particular instant the outer walls had cooled from 1,600° C. to 600°, while the average temperature of the inner walls was 1,100°. In the remainder of the undisturbed cooling, say to 20°, the temperature of the surrounding air, the outside has to cool through only 600 — 20 = 580°, while the inner walls have, as a whole, to cool through 1,100 — 20 = 1,080°, or nearly twice as far. Outer and inner walls will arrive at 20° at practically the same time; for so long as the inner walls are above 20° by any appreciable amount, the outer walls will also be slightly above 20°, because through those outer walls must pass the heat which is escaping from within, and that heat cannot in turn pass from those outer walls into the surrounding atmosphere, which is at 20°, unless those outer walls are themselves above 20°; for in effect heat, like water, will flow only from a higher to a lower level. Thus the inner walls, as a whole, have to cool through 1,080° while the outer walls are cooling only through 580°; this journey the outer and inner walls must make in practically the same time; so that clearly through at least part of their longer journey the inner walls must travel faster than the outer ones.

Consider the case of a horizontal tube, Fig. 3, full of water, which is held in by a tight cork. Withdraw the cork and the level of the water in the very mouth of the tube at first falls very fast, much faster than the level within the tube; but soon the level in the mouth grows nearly stationary, while the level within falls progressively, and falls faster than the level in the mouth.

§ 10. *The piping period.* And this brings us by an easy stage

he piping period. As the amount by which the cooling the consequent tendency to contraction of the outer walls un those of the inner walls progressively lessens, first the re- ance which the lagging contraction of the inner walls offers he faster contraction of the outer walls grows less and less, hat the virtual expansion of the outer walls becomes slower slower, and the outward pressure of the inner walls against n lessens correspondingly. Soon the rate of cooling of the er walls catches up with that of the outer ones, so that the ner cease to press outwards against the latter, and to in- se their virtual expansion; the outward pressure of the er against the outer walls falls to zero; and the virtual ex- sion of the outer walls ceases to increase. The outer walls have "got their growth," as we say of a young man; and ugh henceforth their actual di- nsions continue to shrink, this no re effaces the virtual expansion ch they have now undergone n the natural shrinkage of the nt's stature in old age makes him se to tower above his pigmy class- tes, whom age is shortening with cruelty.

FIG. 3.—RATE OF FALL OF THE UPPER SURFACE OF WATER IN DIFFERENT PARTS OF A TUBE SUDDENLY UNSTOPPED.

The fall of the upper surface is at first most rapid in the mouth of the tube, but later most rapid in the interior.

And next, as the rate of cool- and contraction of the inner ls outruns that of the outer ones still further, the volume of inner walls plus that of the still molten lake ceases to fill pletely the outer walls. And now the pipe begins to form: the excess of contraction of the inner over that of the outer lls makes these inner walls draw outwards, as explained in next section, and so enlarges the cavity between the inner lls in which lies the submerged molten lake. This lake, refore, ceases to fill its cavity completely, so that its upper face begins to descend, its tide to ebb.

§ 11. *The contraction of the inner walls enlarges the central cavity.* at this contraction of the walls of a cavity may result in expansion of the cavity itself, is clear when we consider a se like that sketched in Fig. 4, a block of soft india rubber th a cavity which normally has the shape *abcd*, shown in tted lines. By means of the strings, *he*, *kf* and *lg*, we stretch

the rubber inwards and lessen the cavity by deforming it into the shape shown by the full line, *aefgd*. If these strings are now released, the rubber which their pull has expanded will contract back to its original shape, but in thus contracting the walls of the cavity draw apart from the shape *aefgd* to the shape *abcd*, and the cavity itself thus expands.

Or consider the case of a bottle with its outer walls of glass, which, though itself expanding and contracting with changes of temperature, is at each temperature rigid and unyielding. Consider further that to the inner walls of the glass is firmly welded a thick lining of soft india rubber, which reduces by

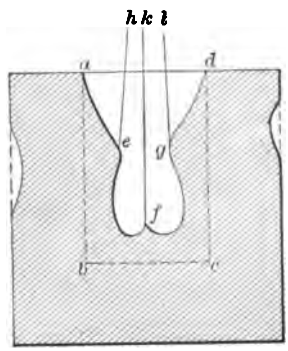


FIG. 4.—THE CONTRACTION OF THE WALLS OF A CAVITY ENLARGES THE CAVITY ITSELF.

The inner walls of the cavity, *abcd*, in a hollow block of soft india rubber are here supposed to have been drawn inwards by means of the strings *he*, *kf*, and *lg*. On releasing those strings, the contraction of the india rubber in returning to its original shape enlarges the cavity to its original size.

perhaps one-third the holding-capacity of the bottle. If the glass shell expands, it draws the rubber after it and enlarges the cavity; if it contracts, it pushes the rubber inwards and lessens the cavity. But if, while the glass shell remains constant in volume, the rubber lining expands, since the rigid glass walls prevent it from moving outwards, its expansion takes place inwards, lessening the cavity; while if it contracts, since it cannot draw the glass walls inwards, its contraction makes it draw out towards those walls, and thus enlarges the cavity.

To sum this up:

$$\text{If the} \left\{ \begin{matrix} \text{outer} \\ \text{inner} \end{matrix} \right\} \text{walls expand they} \left\{ \begin{matrix} \text{enlarge} \\ \text{lessen} \end{matrix} \right\} \text{the cavity;}$$

f the $\left\{\begin{matrix}\text{outer}\\ \text{inner}\end{matrix}\right\}$ walls contract they $\left\{\begin{matrix}\text{lessen}\\ \text{enlarge}\end{matrix}\right\}$ the cavity.

uring the pipe-forming period the rate of contraction and the equent tendency to outward movement of the inner walls outrunning the rate of contraction and the consequent tend- to inward movement of the outer walls. This causes the osite shores of the cavity which contains the molten steel raw apart outwards, and thus enlarges the cavity between e shores, so that the molten lake ceases to fill this cavity pletely, and its upper surface, instead of pressing against top of the cavity in which it lies, begins to sink down from top, its tide begins to ebb, and thus begins the pipe, as ched in Fig. 1.

s this state of affairs continues, so does the pipe continue rm. The sum of the contraction of the inner walls plus that he molten lake continues to outrun the contraction of the r walls; the inner walls plus the molten lake fall further further short of filling the outer walls, and therefore the or cavity, which represents this deficit of volume, continues row, and the level of the molten lake continues to fall, nar- ing all the time, as layer after layer of the lake freezes nst its own shores.

12. *Summary.* We have now seen in § 7 how the resist- of the initially slower-cooling inner walls virtually expands faster-cooling outer ones; in § 8 that this virtual expansion ersistent; in § 9 that later the inner walls in turn cool faster the outer ones; in §§ 10 and 11 that the excess of con- tion of the inner walls in this later period, welded as they to the outer ones, enlarges the cavity between those walls, hat the molten lake between them, which itself is contract- ceases to fill this cavity fully, its tide ebbs, its surface falls, this ebb causes the pipe.

advise most readers to skip §§ 13 to 16 A, inclusive, pp. 183 96, because the discussion is very technical and the reason- very close.

13. *The effect of expansion at or near the freezing-point on the me of the pipe.* In reaching our conclusion that (1) the vir- expansion of the outer walls, due to their fact that their ling at first outruns that of the inner walls, joined to (2) the

excess of contraction of the inner walls over that of the outer walls in the latter part of the solidification, gives rise to a pipe, we assumed for simplicity that the contraction was continuous and uniform in passing the freezing-point, as indicated by the line *GH* in Fig. 5. Let us next ask how the volume of this pipe should be affected by interrupting this uniform contraction, and replacing it for a time with expansion. To most readers it will at first seem self-evident that any expansion at or near the freezing-point must lessen the pipe, and not a few will impatiently brush aside any objections to this inference. But a closer examination shows that the matter is not to be disposed of so lightly. In particular we must not forget that

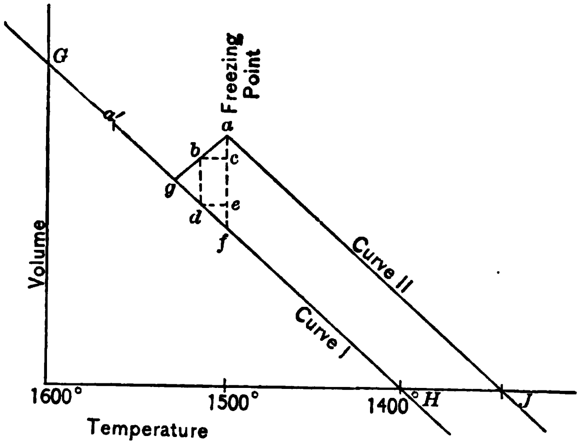


FIG. 5.—EXPANSION ABOVE THE FREEZING-POINT.

such an expansion, though when it is occurring in the freezing of the axial metal it certainly tends to lessen the pipe, must also have previously occurred in the freezing of the outer shell at the time when it froze, and must thus have tended to increase the pipe; because after all the pipe represents simply the difference in volume between the outer shell of the ingot and the interior which is the contents of that shell. The pipe is simply the deficit by which the volume of the interior falls short of filling the shell completely, at the moment when the last of the axial metal has become too solid and strong to be further opened or shut by the interstratal movements of the ingot.

To clarify our ideas, let us consider the case of a nest of

w concentric brass spheres, each fitting exactly over ne next inside it. No matter how such a nest of spheres be made; leave that to me, and simply picture such a nest ur mind. If heat is applied from outside, the outer sphere nds and gapes slightly away from those within it; but if, nstance, the whole nest is immersed in boiling-water and here till the very center has reached 100° C., then in the heating will have sent a gradual wave of expansion the surface of the outer sphere radially inwards to the r of the inner sphere. This expansion will have expanded the outer sphere, and in turn each successive inner one, finally the central one, until at the end, when all have ed 100°, all will have expanded exactly alike, and each it the next one inside it, its neighbor, quite as exactly as in the beginning. The wave of expansion will have exed all the members of the nest, not all simultaneously, but ie time all proportionally. Had there been a hollow or in the inner sphere, and had this sphere alone expanded, had the outer ones, not expanding, forcibly resisted this nsion and prevented it from taking effect outwards, then it d have pressed inwards, and this would have tended to n that pipe; but a wave of expansion which gradually travinwards, expanding each sphere in turn proportionally, d not thus tend in the least to close any such initial pipe e central sphere.

is conception or its equivalent is almost necessary to a understanding of the subject, and the reader should not on till his mind admits the truth of this picture as abso- unquestionable.

ose who say glibly that expansion at or near the freezing- must tend to close the pipe, forget that this same expanmay already have increased the pipe-forming tendency by quivalent amount, when it correspondingly expanded the ng outer crust of the ingot. We must therefore look er, and see in what indirect way this expansion may affect olume of the pipe. In particular, let us note that a freezngot differs from our imaginary nest of brass shells in g cohesion between each layer and the adjoining lay- Therefore, let us ask in particular how this interstratal ion may affect the result. We shall find that careful

study is needed to permit us to draw any inferences, and those of us who are cautious will even then take these inferences with some reservation.

Let us divide our question into three parts, asking first the effect of an expansion which takes place wholly above the freezing-point; next, the effect of one which takes place wholly at the freezing-point; and, finally, the effect of one which takes place wholly below the freezing-point, as sketched in Figs. 5, 7 and 9, respectively (pp. 184, 191, and 193).

§ 14. *Case* 1, *the expansion takes place wholly above the freezing-point.* Here our question is, "How is the volume of the pipe affected by a change in the volume temperature-curve, from the line *GgH* to the line *GgaJ* of Fig. 5?"

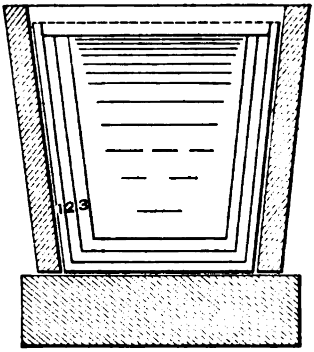


FIG. 6.—THE FREEZING OF A MASS CONSIDERED AS A NEST OF CONCENTRIC SHELLS.

Let us consider the molten metal as made up of a series of concentric shells, Fig. 6, assuming for simplicity that each of these is at uniform temperature throughout.

Sub-case A. As the metal begins to freeze, it is by diligent stirring brought to exactly uniform temperature throughout, so that it is represented by the point *a* in Fig. 5. Each layer, as it now freezes and cools, will travel down the line *aJ*. But, as this line is exactly parallel with *gH*, the line which would have been followed if the expansion had been continuous and uniform, each layer in thus cooling through the same number of degrees will undergo the same amount of contraction in both cases, so that substituting *GgaJ* for *GgH* really has no influence on the contraction at all, and therefore none on the size of the pipe. In other words, because by assumption the whole of this expansion in cooling has taken place before the freezing

lly begins, and because it is only the conditions which ex-
ıring freezing that lead to formation of the pipe and affect
e, this expansion can have no effect on the pipe. If the
GgH would lead to a pipe, the volume of which would be
cent. of that of the ingot itself, the line *GgaJ*, if in effect
s begins only at *a*, also will give a pipe of which the vol-
will be 3 per cent. of that of the ingot. In short, the
ve volume of the pipe is unchanged; but, as the expan-
ga, increases the absolute volume of the ingot, so will it
se in like ratio the volume of the pipe.

-*case B*. When the outer shell (1 of Fig. 6) is beginning
eze—*i.e.*, is at temperature *a* of Fig. 5—the interior is at
ratures between *a* and *g*, and its average temperature is *b*.
bvious effect of this supposed increase of volume before
ing the freezing-point, is to make layer 1 lighter than the
o that it swims to the upper surface. But to simplify our
, let us assume that the heat is removed so rapidly from
utside that this upward swimming of the cooler and
r parts has not time to take effect to any important ex-
so that each of the concentric shells, 1, 2, 3, etc., of Fig.
nains in place during the cooling and freezing.

ien the infinitely thin shell 1 reaches temperature *a* with
II. it is larger by the distance *af* than it would have
with curve I. But the dimensions of this still liquid shell
determined, not by the expansion which it has now un-
ne, but by that which the average of the metal within it
ndergone. If, for the moment, we conceive that, follow-
urve II., this shell 1, expanding more than the metal
ı it, raised its edges above the level of that metal, as
ıed in dotted lines in Fig. 6, we see that the metal which
hus raised above the general level would at once sink to
evel, of course raising that level proportionally. By like
ning, if curve I. is followed, the volume of the outer
when it had fallen to temperature *f*, would be determined
volume *d* of the interior at its average temperature, as-
l as *d*, temperature *b* and temperature *d*, of course, being
cal. At this moment, then, the outer shell becomes solid,
ezes; and this first solid outer shell is just large enough
tain the still molten interior.

the further cooling, the difference between the behavior

with these two curves is that with curve I. the natural contraction of the interior in further cooling from d to f exceeds that of shell 1 by ef, whereas with curve II. it falls short of the natural contraction of the shell 1 by ca. Now, if the natural contraction of the shell could take place unobstructed, the effect of this difference ought to be to diminish the pipe by an amount corresponding to the sum of ef plus ca. In other words, with curve II. the outer shell 1 is naturally larger by ce than it is with curve I., because the interior is thus larger at the moment when freezing determines the initial volume of the shell; but the interior, when it in turn reaches the freezing-point, will be larger by af with curve II. than with curve I.; so that substituting curve II. for curve I. implies increasing the volume of the interior, as it reaches the freezing-point, relatively to shell 1, by $af - ce$; and the fact that this is equal to $ef + ac$ confirms the inference reached in the preceding sentence.

The volume of the pipe, as we have already seen, is the difference between the volume of the outer inclosing shell and the volume of the contents of that shell at the time when the contents is just reaching that degree of rigidity which prevents further change of the volume of the pipe. In this particular case when, in freezing, the dimensions of the outer shell are determined by that of the still-liquid interior, the material which composes that shell has already done its expanding, which takes place wholly above the freezing-point. Therefore, if the molten interior could now be removed from within this first formed shell, the shell itself would henceforth contract in following curve II. exactly as it would have done in following curve I. From now on the substitution of curve II. for curve I. has no effect on the contraction which the outer shell would follow if unobstructed. The outer crust travels down aJ, quite as if it were traveling down gH.

But, while the material which composes the outer shell has now already done its expanding, that which composes the interior has not. From this time on, the substitution of curve II. for curve I. means that the net contraction of the interior is lessened by $ef + ac$. This lessening of the contraction of the interior should lessen the volume of the pipe by $ef + ac$, and the lessening should persist through any and all subsequent changes of volume.

That this last assertion is true is seen by comparing the cases two trees, growing at very different rates, with different and nplex variations of rate in different seasons. If the pot in ich one tree is standing is arbitrarily lowered 1 ft. below that which the other stands, this initial difference of 1 ft. will inge all the subsequent differences of height between these trees by exactly 1 ft., no matter how complex may be the iations of growth of either tree.

The foregoing reasoning is based on the supposition that the ural contraction of the outer crust is unobstructed. Yet it arly must be obstructed by the expansion of the metal within which must tend to stretch it. If this stretching did not exd the existing elastic limit of the outer shell, the obstrucn would be only temporary, and at the end the pipe would ually be lessened by the amount $ef + ac$. But most metals ve so low an elastic limit when they have first frozen, that ich of the stretching of the outer crust by the expansion of interior must result in a permanent set, and thus be pernently effective.

In the early part of the freezing, even of a material which ntracts continuously and uniformly past the freezing-point, more rapid cooling of the crust than of the inner walls ngs about, as we have seen (§ 7), a virtual expansion of se outer walls. I have likened this to shrinking a tire upon wheel which is contracting, but contracting more slowly than tire itself. But in our present case the expansion which interior is undergoing as it approaches the freezing-point gravates the matter, which must be likened to shrinking a e upon a wheel which itself is expanding.

Thus, in the early part of the freezing, much of the relative pansion, $ef + ac$, of the interior relatively to the outer crust pends itself in increasing the expansion of the crust, perhaps en turning a virtual into an actual expansion. It is only in latter part of the solidification, when the rate of cooling the interior has not only caught up with that of the outer ell, but has so far outstripped it that the average rate of conaction of the inner walls exceeds that of the outer walls by amount greater than the simultaneous rate of expansion of e still molten interior—it is only then that the excess, $ef + ac$, the contraction of the interior will begin to take effect in

lessening the volume of the pipe. But some remainder of this expansion will do this, quite as a stream cannot rise above its source. It is to be remembered that, as long as the expansion of the molten interior is resisting the contraction of the crust, so long is the beginning of the formation of the pipe postponed, because no vacant space can arise while the molten interior is still pressing against the contracting shell.

Here is another way of looking at it, which leads to the same conclusion. Substituting curve II. for curve I. causes an expansion of the interior relatively to the crust by $ef + ac$. This will in turn lead to an expansion of the crust, not by the whole, but by part only, of $ef + ac$; and the remainder of $ef + ac$ is therefore an effective lessening of the pipe.

This general result is the same whether we imagine that the freezing takes place not only at the bottom and sides of the ingot, but also equally rapidly at its top; or whether we imagine that the top does not freeze over till the very end of the freezing. In the latter case the expansion of the interior, instead of increasing the virtual expansion of the outer walls in every direction, simply raises the level of the upper surface; but this, too, must eventually freeze over, and when it does freeze its previous rise will have increased the total volume of the ingot quite as much as in the other case.

In short, of the excess, $ef + ac$, of the expansion of the interior, part will be consumed in increasing the volume of the shell, and only the remainder will take effect in lessening the volume of the pipe.

To sum this up, if (sub-case A) the metal is all brought to the freezing-point at the same instant, expansion before freezing can have no effect on the volume of the pipe. If (sub-case B) at the moment when the outer crust freezes the interior is somewhat above the freezing-point, then part of its expansion in approaching the freezing-point will result in expanding the crust itself, but still part of its expansion will take effect in lessening the pipe.

§ 15. *Case 2, the expansion takes place wholly at the freezing point*, at the instant when the metal is passing from the liquid to the solid state, substituting curve III., Fig. 7, for curve I. This introduces a wholly new and different condition: that the layer which at any instant is expanding by the distance ga is

now solid metal, tending to retain its own shape and dimensions, instead of being liquid, as in case 1, and flowing to conform with whatever mold surrounds it. Moreover, each layer in freezing and expanding may be assumed to cohere strongly

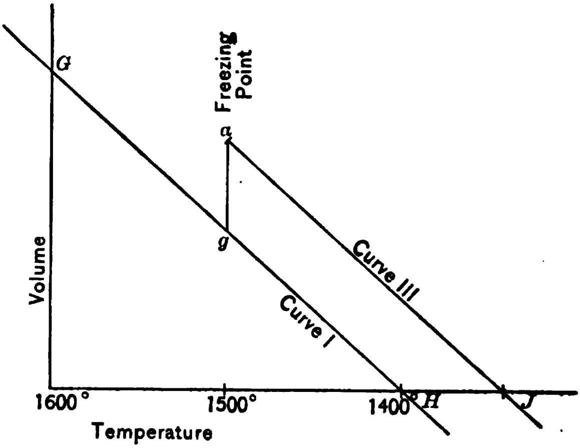
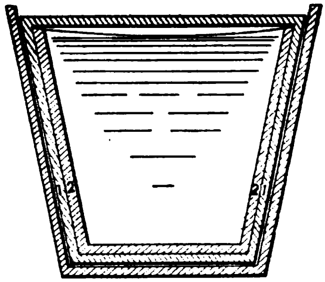


FIG. 7.—EXPANSION AT THE FREEZING-POINT.

with the solid layer outside it, but not to cohere strongly with the still molten layer inside it.

Were it not for this second consideration, the case would seem to resemble that of our nest of hollow brass spheres, one within another, considered early in § 13. But in case 2 the cohesion of the layer which is freezing and expanding with



. 8.—THE FREEZING OF A MASS WHICH EXPANDS AT THE FREEZING-POINT.

e layer outside it, which has already frozen and finished its pansion, may be expected to add to the expansion of that ter layer. Thus, in Fig. 8, the outermost layer of all, 1, hen it starts to freeze has the dimensions of the still-molten ass within; but in the act of freezing it expands. Each of a

series of infinitely thin layers will be freezing and expanding only an infinitely short time, so that the expansion of each will be finished before that of the next begins. But these layers, though infinitely thin, are of very considerable length, nearly the length of the ingot itself, so that the amount by which each expands is considerable. Layer 1 in freezing, therefore, raises itself up above the surface of the still-molten mass within it, so that a narrow empty space tends to form between the top of the molten metal inside and the crust of shell 1, which now incloses it. Layer 2 in freezing in turn tries to expand, but its expansion is interfered with by its cohesion with layer 1. The result of such an interference is a compromise; the expansion of layer 2 takes place, but not to its full extent: in so far as it takes place it expands layer 1, which thus remains in tensile stress, and in so far as the expansion is suppressed layer 2 is shortened and prevented from reaching its natural growth, or is virtually compressed, and remains in compressive stress. Next comes layer 3, which in turn tries to expand, and acting through layer 2 throws additional tensile stress on layer 1, and expands it further; and so on with each successive layer. In so far as this action expands the outer crust, it tends to increase the pipe, like any other form of virtual expansion of the crust.

And this, it seems to me, is the natural result of an expansion which is strictly limited to the instant of solidification. It is true that, as solidification proceeds, the influence of the expansion of each successive freezing-layer in virtually expanding the outer shell is less and less, because that outer shell is always growing colder and hence stronger; so that a larger and larger proportion of the natural expansion of each freezing layer takes effect in making that layer bulge inwards and thus lessen the pipe. But even if the expansion of each and every layer, including the outer one, was its full natural expansion, we should reach only the condition of our nest of progressively heating and expanding solid brass shells, which, when all have heated and expanded alike, just fill and fit one another exactly as they did before any expansion began. If there were no cohesion between the successively freezing layers, the effect of a wave of expansion which traveled inwards from layer to layer and ended at the central last-freezing point

st as that point froze would be *nil*, for it would expand each ccessive layer just proportionally to every other layer. Therere if, as I suppose, the cohesion of each freezing layer has a rtain effect in expanding the layers outside it, and this in rn leads to some expansion of the outer shell in excess of the rmal, then, however slight this excess, it should add itself to e volume of the pipe, because the expansion of the interior nnot exceed the normal, and thus cannot make up for the cess of expansion of the crust.

§ 16. *Case* 3, *the expansion takes place wholly after solidifica-n*, so as to substitute curve IV. of Fig. 9 for curve I., but yet t very long after solidification, so that at the time when the

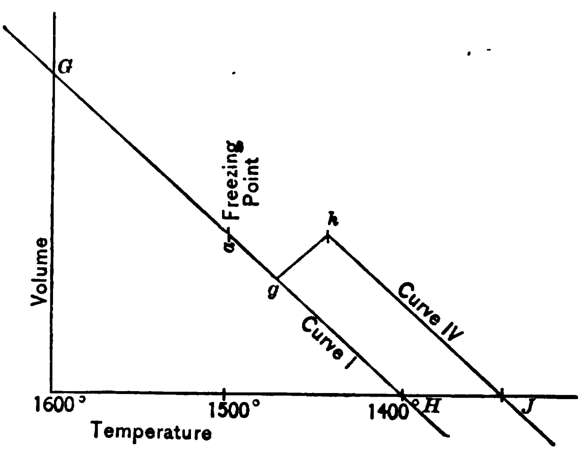


FIG. 9.—EXPANSION BELOW THE FREEZING-POINT.

ter shell is thus expanding from g to h, much of the interior still unfrozen.

Here first a wave of solidification or freezing sweeps gradu-y through the ingot, from its outer shell inwards to the last-ezing point; and, after this first wave has started to sweep vards, but before it has reached the axis of the ingot, a sec-d wave, an expansion, follows the first.

If the ingot were composed of a nest of wholly unconnected ncentric shells, this wave of expansion would have no effect the relative volume of pipe and ingot. Each shell would pand in exactly the same proportion as every other shell. If e expansion were, for instance, 3 per cent., the absolute volume ingot and of pipe would expand by 3 per cent., and the ratio

of pipe to ingot would be unaffected. The question before us then is, "How does the cohesion which exists between the different layers affect this result?"

As the outer shell starts to expand from *g* towards *h*, its cohesion with the cooler layers within it, which are still contracting, because they are still moving in the direction *ag*, impedes its expansion and throws it into compressive stress, while by this same fact the layers within it are thrown into tensile stress, and slightly expanded beyond their natural dimensions. When layer 1 begins to contract from *h* towards *J*, layer 2 within it is traveling up from *g* towards *h* and expanding, and its expansion is in turn resisted by the contraction of layer 1, and by that of layer 3, which is traveling in the direction *ag*, and so on. Thus the tendency of each successive layer to expand is impeded by its cohesion with the neighboring ones which are simultaneously tending to contract, so that this wave of expansion is (1) immediately preceded by a wave of tensile stress, is (2) accompanied by a wave of compressive stress, and is (3) immediately succeeded by a second wave of tensile stress.

If these several stresses did not reach the existing elastic limit of the material as the wave gradually swept inwards, so that layer after layer reached *h*, and in turn traveled thence towards *J*, these stresses would eventually efface each other when the innermost layer of all had reached *h*, because every layer would have undergone the same expansion. Therefore, our next question is, "If the stress is in excess of the elastic limit, what relation will this excess in the outer layers bear to the excess in the central layers?" This we ask, because it is the difference between the volume of the outer shell and that of the interior that determines the volume of the pipe.

Now there is one extremely important difference between the conditions of the outside and those of the deep-seated interior, at the respective times when each is expanding from *g* to *h*; and that difference is that the wave of expansion travels much more rapidly in through the quickly cooling shell of the ingot than through the relatively-slowly cooling deep-seated parts. On this account, for a given distance between two neighboring layers, the temperature-difference will be much greater in the outer layers at the time when the wave of expansion is passing there, than in the deeper-seated layers when the wave

turn reaches them; and the greater the temperature-differ-ence, the greater will be the stress set up by the wave of expan-sion, the greater also will be the amount by which that stress exceeds the elastic limit of the material, and hence the greater will be the permanent set, whether in tension or in compres-sion, which is set up. Therefore, the permanent set, if there is any, will be greater in the outside layers than in the deep-seated ones.

Will this permanent set be a compression or an extension? What concerns us chiefly is the permanent set in the very out-side layer, and this, it seems to me, must be a compression, be-cause at the moment when the very outside layer is expand-ing, its expansion is resisted by the tendency of the whole of the material within it to contract. Indeed, unless the expan-sion which we are imagining, *gh*, is a most extraordinarily great one, it seems to me that the permanent set in compres-sion should exceed that in extension throughout the whole travel of the wave from outside to axis, because the number of layers which at any given moment are trying to expand is much smaller than the number of those which at that moment are trying to contract; in other words, the resistance of the tem-porary majority of the layers, the party of contraction, should outweigh that of the minority, the party of expansion; and, though each may whittle down the influence of the other, the expanding tendency of the layers which are expanding causing slight permanent extension in those which are trying to con-tract, and *vice versa*, yet in each of these struggles the greater whittling down will be done by the layers which are tempo-rarily in the majority, and this will always be the party of con-traction.

The sum of this is that greater permanent set is to be ex-pected in the outer shell than in the interior, and that this set should be chiefly in compression; or, in short, that the effect of an expansion after solidification should be to lessen the volume of the outside shell rather more than that of the interior, and this evidently should tend to lessen the volume of the pipe.

§ 16, A. *Case 4, the expansion takes place in the freezing-range, as distinguished from the freezing-point.* Here I refer to the fact that the freezing of carburized iron, like that of most alloys, takes place not at a single point but through a very consider-

able range of temperature, which, in case of iron containing 2 per cent. of carbon, reaches from 1,130° to 1,325°. In this case, at any given instant during freezing, there is a series of concentric shells, all of which are in this freezing-range, and all of which, therefore, are freezing. The layer which at this instant forms the boundary of the molten lake is just beginning to freeze; and as we pass outwards the freezing of each successive layer has, at this same instant, gone somewhat further than that of the layers within it.

Of these several freezing layers, only the innermost, or a few of the innermost ones, truly come under our case 2, the essence of which is that the freezing and expanding layer does not cohere with those within it, though it does cohere with those outside it. All but a few of the innermost of the layers, which at any given instant are freezing, fall under case 3, in which the expanding layer coheres both with those outside and with those inside it.

If freezing covers any considerable range of temperature, then the number of layers which thus fall under case 3 should be far greater than the number of those which belong under case 2; so that the net effect of the expansion, like that of case 3, should be to lessen the pipe.

The freezing of gray cast-iron probably belongs to this case 4. The floating of the graphite, set free during solidification, tends to show that there is expansion at the very moment when freezing begins, because the graphite, if it were not set free until freezing had progressed far, or until it had ended, would be mechanically prevented from rising to the surface; and the formation of so light and bulky a substance as graphite in the freezing metal must make it expand. Beyond this, the general experience of the annealing process for making malleable cast-iron, like the behavior of black-heart file-steel, tends to show that the formation of graphite continues at temperatures considerably below the end of the freezing-range proper.

§ 17. *General summary of the influence of expansion at or near the freezing-point.* To sum up the foregoing discussion:

If the expansion takes place wholly	The effect on the pipe will be
, A. Above the freezing-point, and the whole is ought to uniform temperature before freezing gins..	*Nil.*
, B. Above the freezing-point, and the whole is t brought to uniform temperature before freezg begins..	To lessen it.
. At the freezing-point.....................	To enlarge it.
. Below the freezing-point...........................	To lessen it.
. Through the freezing-range......................	To lessen it.

ius expansion tends to lessen the pipe in all except the cases in which it takes place either wholly above the freezoint in a liquid brought throughout to constant tempera, or at the true freezing-point of a pure substance, which y freezes at a single point instead of through a range of erature.

18. *Moissan's evidence.* The reasoning which we have been wing puts us in a position to consider Moissan's evidence, h led him to infer that, although cast-iron containing 7.65 to 8.17 per cent. of carbon does expand in solidi-, yet steel containing less than 1 per cent. of carbon does but follows the general law and contracts. His evidence effect that, whereas a button of such cast-iron in solidify-in the air bursts its shell and spurts out a considerable of molten metal, yet a little button of steel, made by melt-500 g. of pure Swedish wrought-iron in a magnesia cru-, does not thus burst its shell, but becomes hollow (*se creuse*) solidifies without the escape of anything from its interior. expulsion of the molten cast-iron from the solidifying cast-button he properly refers to the expansion of the freezing ior, which, taken jointly with the evolution of gas in freez-and the fact that the cooling and contraction of the outer t outrun those of the interior, suffices to burst open the racting outer crust.

ut the phenomena can readily be explained on the hypothe-hat steel does expand in solidifying, especially if we con-that its expansion ought to be less than that of cast-iron, expansion of which should be increased by the formation raphite within it.

hus, first, he found that like buttons of gray cast-iron, if

cooled suddenly, did not always eject anything from within; which may be taken to mean that, even with the greater expansion of this cast-iron in freezing and with the weakness and brittleness of the inclosing envelope itself (that is to say, the outer crust of already solid cast-iron), yet under favoring circumstances this weak and brittle cast-iron crust suffices to resist so completely the expansion of the freezing metal within that this crust is not broken through, and none of the molten iron from within escapes. If this is possible under favoring conditions with so brittle a crust, and with such great expansion as we have in case of cast-iron, it is not at all surprising that the far stronger and more ductile outer steel shell of a solidifying steel button should suffice, under less favorable circumstances, to resist unbroken the much slighter expansion of the freezing steel within it.

The reasoning which we have studied suffices to show that a pipe or other hollow space may well form even in materials which expand in freezing. The presence of a pipe in very graphitic cast-iron is no rarity; so that the fact that the metal becomes hollow (*se creuse*) is no proof that it does not expand in solidifying.

§ 19. *The crust which covers the top of the pipe in steel ingots.* The fact noted in § 5, that the pipe in steel ingots, except in very narrow ones (§ 38), instead of being open at the top like those in Fig. 15, is covered by a crust, often of considerable thickness, at first suggests that the metal expands in freezing. It certainly does imply that the upper surface of the molten steel, instead of beginning to sink down as soon as the outer walls of the ingot begin to solidify, remains level long enough to freeze across. But this I refer, not to the expansion of the steel itself in solidifying, but to the fact that the more rapid cooling of the outer than of the inner walls at the beginning of freezing forces these inner walls inwards, and so raises the level of the molten metal, or at least prevents it from sinking. The failure of the upper surface to sink at once is probably due, not to the expansion of the molten metal itself, but to the squeezing inwards of the inner walls of the ingot by the now more rapid contraction of the very outer crust.

§ 20. *Can a substance which expands at or near the freezing-point yet form a pipe?* It clearly can. All that is necessary is

the pipe-forming tendency, due to the virtual expansion e outer crust, shall exceed the pipe-closing tendency, due e expansion near the freezing-point. But, though this exon, according to our reasoning in §§ 13 to 16 A, may lessen ipe, as is illustrated by the fact that gray cast-iron, which nds apparently shortly below the freezing-point, pipes less white cast-iron, yet whether it shall efface the pipe or not nds on the strength of the pipe-forming tendencies.

1. *What arrests the down-stretching of the pipe?* At first the ning in § 11, p. 181, seems to prove too much, implying that ipe ought to reach nearly to the very bottom of the ingot, eas, in fact, it very rarely reaches down one-third of the Thus, considering any given horizontal layer, for ine, layer V. in ingot *E* of Fig. 1, by our reasoning when xial part, 3, reaches its freezing-point, the inner walls 2 should still be cooling faster than the outer walls 1 and nd by as much as their contraction at this time is outrunthe contraction of 1 and 5, by so much should this layer, whole, be drawing outwards, and tending to tear itself in its central region, 3, and thus to cause a cavity in 3, or, ort, to prolong the pipe down into 3. Why, then, does ipe stop just short of this layer?

ere are five causes which may co-operate to arrest the -stretching of the pipe. They are:

The hypothetical possible expansion of the axial metal at noment of freezing;

The in-pressing of the ingot's sides by the atmospheric ure;

Blow-holes;

The down-sagging of the metal from above; and

In the lower part of the ingot, the lagging of the solidifin of each layer behind that of the layers beneath it, or, in words, the fact that solidification is proceeding from below rds.

ese five causes we will now take up in §§ 22 to 30.

22. *Cause* (1). *The expansion of the axial metal in the act of fying*, might, indeed, contribute to arresting the downching of the pipe at layer VI., and thus to preventing it entering layer V.

order to fix our ideas, let us hypothetically assume that steel

expands near the freezing-point, as sketched in Fig. 10. If this is assumed, then it might well be that the expansion of part 3 of layer V., in the act of freezing and climbing from *c* towards *e* of Fig. 10, contributes more efficiently towards compensating for the simultaneous outward drawing of parts 2 and 4, than the corresponding expansion of the axial part of layer VI. In layer VI. this expansion of the axial part may not have been so well timed for its like work of compensating for the outward drawing of the inner walls.

But this cause in and by itself does not suffice to explain

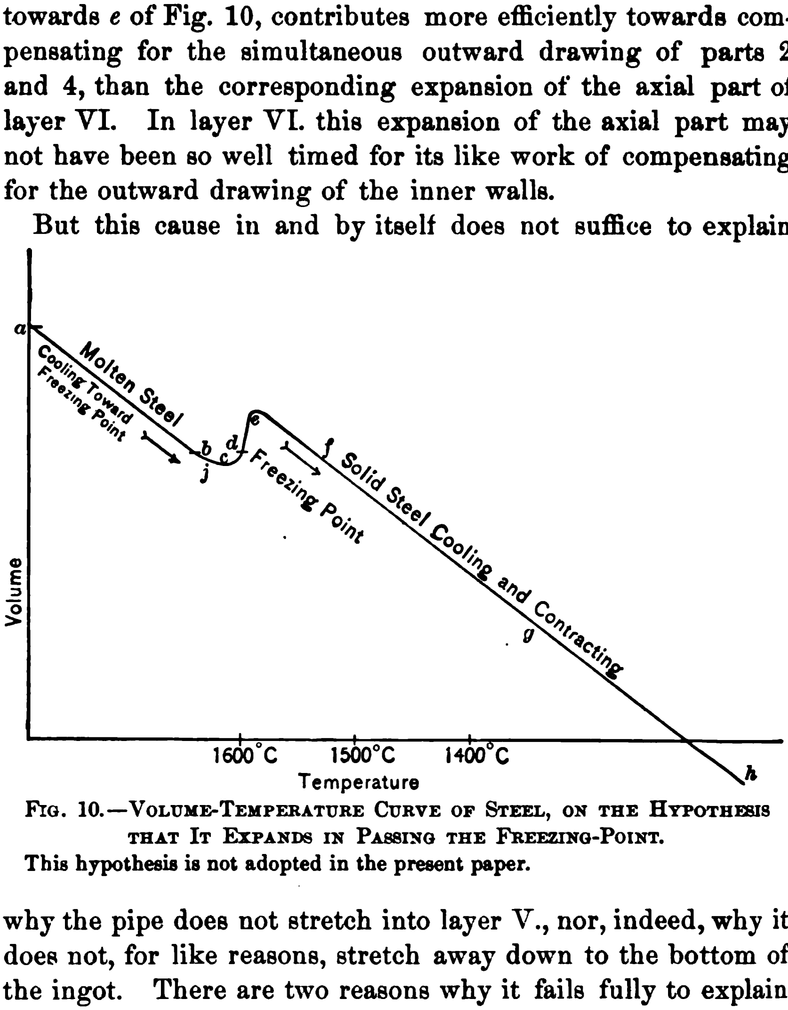


FIG. 10.—VOLUME-TEMPERATURE CURVE OF STEEL, ON THE HYPOTHESIS THAT IT EXPANDS IN PASSING THE FREEZING-POINT.

This hypothesis is not adopted in the present paper.

why the pipe does not stretch into layer V., nor, indeed, why it does not, for like reasons, stretch away down to the bottom of the ingot. There are two reasons why it fails fully to explain the arrest of the pipe. The first of these is that at the time when part 3 has passed the crest *e* of Fig. 10, and has again begun to contract with its further cooling, the metal there is still so weak and mushy that it ought to draw apart under the continued outward stress due to the continuing outward pull of parts 2 and 4; so that after all a cavity ought to form in this layer V., or, in short, that the pipe ought to reach down into this layer. And what is true of this layer ought, by like reason-

o be true of each following layer downwards towards the m of the ingot. So that, wherever the pipe happens to he question remains, " Why did it not go one step deeper ? "

second even more cogent reason why the expansion of the in freezing does not suffice to explain fully the arrest of ipe, is that, whereas nearly all substances, so far as I have ed, pipe in freezing, yet in none of them does the pipe h down nearly to the bottom of the ingot, unless, indeed, onditions are unusually favorable to its down-stretching. unless we are prepared to go to the length of assuming that f these varied substances—metals, alloys, slags of all , wax, paraffine, sulphur, and what not—also expand at the ent of solidification, this explanation breaks down, and further explanation is needed.

short, the expansion of gray cast-iron and ice at the ent of solidification may help to arrest the down-stretching e pipe in these substances; but we must look to some ional explanation for this arrest in the miscellaneous sub-es which, though piping, yet like cast-iron do not pipe to treme depth, and unlike cast-iron do not expand in freez-nd this additional explanation should apply to ice and ron also.

3. *Cause* (2). *May the atmospheric pressure help to arrest the stretching of the pipe?* In case of an ingot like that shown g. 11, the tendency of the pipe to stretch down below the t point which it actually reaches may have been restrained e bulging-in of the walls of the ingot from atmospheric ure. This is easily understood in this particular case, be- the pipe is surrounded in every direction, above and be-s well as on its sides, by a thickness of solid metal too to permit any rapid infiltering of atmospheric air to fill acuum which the gaping of the pipe tends to cause. Of e, this space could not in any case be a true vacuum, be- the gas dissolved in the steel would evolve freely into it et this evolution of gas might be so slow that the actual ure in the pipe would be very far below the atmospheric ure on the outer walls of the ingot; and the excess of the atmospheric pressure over the pressure of gas within the

pipe might press the walls of the ingot in enough to arrest the down-stretching of the pipe.

In other cases we cannot feel so sure that the atmospheric pressure does contribute materially to this arrest of the pipe. For instance, in the ingots shown at *A* of Fig. 22 and in Fig. 12, the crust at the top of the ingot is so thin that the air might either filter in through holes in it or might press in the top itself enough to raise the pressure in the

Taken from Ledebur, *Eisenhüttenkunde*, vol. iii., p. 864, Fig. 287.

FIG. 11.—STEEP-WALLED PIPE IN A STEEL INGOT.

The steepness of the walls of this pipe indicates that it opened after the steel had reached an advanced degree of firmness. The obliqueness of the blow-holes at the sides suggests that they have formed in plastic metal. The pear shape of those at the bottom suggests that their upper part has broken away and floated up towards the top of the ingot. It may be represented by the irregular blow-holes in the upper part of the ingot.

FIG. 12.—VERY NARROW STEEL INGOTS PIPE DEEPLY.

The general smoothness and bell shape of the upper part of the pipe suggest that it formed when the remaining unfrozen metal was decidedly mobile, though of course pasty at its very shores, where freezing was actually taking place. The slight furrows in this part seem to have been formed by the down-sagging of the lately deposited shore-layers as soon as they were left unsupported by the ebb of the tide. The steepness, crystal-facing, and at last discontinuousness of the lower part of the pipe suggest that it formed after the last of the metal had become relatively firm.

pe nearly to the atmospheric pressure. Again, in the zinc gots in Fig. 15, and in many steel ingots (see § 38), the pipe open to the air, so that the outward atmospheric pressure on e sides of the pipe should equal the inward atmospheric pres-re on the outer walls of the ingot.

Thus the atmospheric pressure, while it may often help to rest the down-stretching of the pipe, does not suffice by itself explain why the pipe usually stops so high up in the ingot, en when there are no blow-holes.

§ 24. *Cause* (3). *That blow-holes should lessen the pipe* will be lf-evident to many. For those to whom it is not, let me add at these blow-holes are permanent bubbles which form within e plastic inner walls of the freezing ingot. In so forming ey must in effect puff out and enlarge or thicken those walls; d we have seen that whatever enlarges the inner walls ereby pushes their shores nearer together and thereby les-ns the space between those shores, in which space lies the olten lake. But to decrease this space must raise the upper rface of the lake, or at least must restrict its ebb, and must us lessen the pipe which is the cavity left vacant by that ebb. ee §§ 48 and 49.)

But this does not help to explain why, in ingots of metal parently wholly free from blow-holes, the down-stretching of e pipe is arrested very far above the bottom of the ingot. learly, we are no nearer the end of our search than we were the end of § 22.

§ 25. *Cause* 4. *Sagging arrests the down-stretching of the pipe.* nd this brings us to the fourth of our explanations of the rest of the pipe, an explanation which, from its very simpli-ty, might easily be overlooked, the down-sagging of the tely-frozen parts, at each period during the freezing. This gging tends to fill up any incipient crevice in any given hori-ntal layer as fast as it starts to form, to fill it with molten etal as long as the metal just above that crevice remains olten, and afterwards with pasty metal.

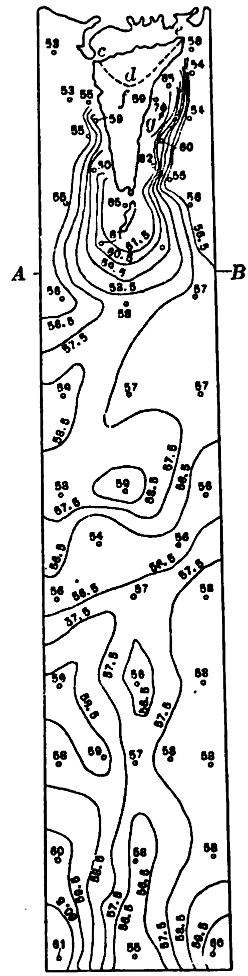
To clarify our ideas, let us follow the freezing of a given layer, y layer I. of ingot *E* in Fig. 1, p. 172. At the moment when e axial part of this layer, 8, is freezing, and tends to neck or gape because of the outward movement of parts 7 and 9, the xial matter just above is still molten and runs down to meet

this necking, gaping or even cracking, moved down not only by its own weight but also by the downward pressure of all the still molten and pasty metal above. And, when even the axial matter in layer II. has frozen, it is still so soft and pasty that the pressure of the molten and pasty metal above presses it down to meet the necking and gaping tendency in the axis of layer I. Thus what really happens is that the axial part of each layer is (1) tending to tear or gape open because of the outward drawing of the parts to right and left of it, and is at the same time (2) forced down to replace the metal which like causes are removing from the axial part of the layer next below, and (3) is receiving fresh metal from the axial part of the layer above, which in turn is pressed down by the weight of all the molten and plastic metal above it. Thus the metal, which was initially in a given horizontal layer, is by this action made to sag somewhat, as is sketched in layer III. The essence of this explanation, then, is that the tendency of each layer to axial gaping, or the gaping tendency, is aggravated by its need of feeding metal down to meet the gaping in the layer beneath, and met by its receiving metal from above.

Whether the pipe shall stretch down into a given layer, then, depends upon whether the overlying molten or pasty metal is fed down fast enough to satisfy the gaping tendency in the axis of that layer. This gaping tendency may be called the pipe-forming tendency, and the down-sagging tendency of the molten or pasty metal the pipe-closing tendency, a tendency to which, as we saw in § 24, the formation of blow-holes contributes. Clearly, as we pass up from layer to layer, the supply of molten and pasty metal from above becomes smaller and smaller, and the weight of the metal above which forces it down becomes less and less. The very lowest layer into which the pipe, in the cold ingot, is found to reach (layer VI. of Fig. 1, *E*) is that in which the supply of molten and pasty steel from above has not sufficed to overcome the gaping tendency; in other words, to make good the withdrawal of the axial metal outwards and downwards, up to the time when that axial metal has become so cool, solid and firm as to endure the outward drawing stress without breaking. The next layer below, V., has received sufficient strength, before the supply of metal from above failed, to endure the outward stress without breaking.

If we assume that the axis of layer IV. ingot *E*, Fig. 1, is the hottest spot in e ingot, so that it is the last to freeze, e isotherms will be grouped onion-wise ound it somewhat as sketched. When e axis of this layer freezes, there will be molten metal above it to run down eely to meet its gaping; but instead sty metal may be fed into it under the essure from above. If, because the in- t is thick, or because its mold has been eheated, or for any other reason the pip- g tendency and the outward-drawing of yer IV. are small, the down-sagging of e pasty metal from above may meet the ping tendency in this layer until its axial etal has grown strong enough not to eak under that outward-drawing stress; , in short, the pipe may not reach to is the last freezing-point, the richest of e segregation. If, on the other hand, e piping tendency is strong, and the pply of pasty metal from above is small, in thin ingots like those of Fig. 22, not ly this layer but even those far below may fissure, because in them the supply pasty metal from above falls short of e demand made by the gaping tendency, a time when the axial metal is still o weak to endure the outward-drawing ess, so that the pipe may stretch far eper than the richest point of the segre- te.

In most of the cases which I have ex- nined, the pipe does not reach down as r as the richest of the segregate—*i.e.*, as r as the last-freezing spot; but in a case ported by Stevenson and Kent,[6] repro- iced in Fig. 13, it apparently reaches far



(A. A. Stevenson and R. Kent, *Trans.*, xxiii., 637.)

FIG. 13.—PIPING, SEGREGATION, AND ISOCARBS IN A STEEL INGOT.

The contour lines here drawn give the approximate position of the carbon-contents which they represent. The numerals in this figure are the carbon-contents, in hundredths of 1 per cent.

[6] *Trans.*, xxiii., 637 (1893).

below this spot. To show the progress of the solidification and the progressive enrichment by segregation, I have plotted in this the lines of equal carbon, or "isocarbs."

§ 26. *Evidence of this sagging action*, which I have been forced to introduce in order to explain why the pipe does not stretch nearly to the bottom of the ingot, is supplied by the nearly vertical furrows, which often line the upper part of the pipe, as shown in Fig. 14, and less distinctly in the upper part of Fig. 12. Each of these furrows is in a nearly vertical plane, which passes nearly through the axis of the ingot, and, taking them

FIG. 14.—THE FURROWS IN THE UPPER PART OF THE PIPE IN AN 8-IN. STEEL INGOT IN THE AUTHOR'S COLLECTION.

as a whole, they are such furrows or tracks as should result from the downward sliding of the viscous, partly frozen steel which the ebb leaves exposed on the shores. As this viscous steel slides down, the progressive narrowing of the converging walls over which it slides should tend to pucker it, thus accenting this furrowing.

One may not speak with perfect confidence about the cause of these furrows. In many cases their shape could be explained by simple puckering due to horizontal contraction; but in the ingot from which Fig. 14 is taken the indications of sagging seemed to me irresistible, after careful study.

27. *Need of an additional explanation.* The four causes h we have now considered: (1) possible expansion of the metal in solidifying; (2) the atmospheric pressure; (3) blow-s, and (4) the down-sagging of the axial metal, do not seem plain easily why the pipe is so short in an ingot of zinc, such shown in Fig. 15, I. and II. Here and in like cases I see

I. II. III.

l5.—INGOTS OF METALLIC ZINC, PREPARED BY DR. WILLIAM CAMPBELL IN THE AUTHOR'S LABORATORY.

three ingots here shown have been sawn vertically through their axes, so show the pipe. Ingot I. has been etched, in order to show the columnar ure. The obliqueness of this structure in the lower part of the ingot shows ooling effect of the bottom of the mold. Ingots II. and III. were made same way, except that the large end was lowermost in II. and uppermost . This difference has lengthened the pipe greatly in ingot II. by making eezing take place from above downwards, and thus impeding the down-sag- of the axial metal to fill the nascent pipe.

eason to suppose (1) that the metal expands in solidifying, cially because the pipe is wholly open at the top. This openness, moreover, seems to exclude the idea (2) that the ospheric pressure on the outer sides of the ingot may have sted the down-stretching of the pipe; (3) no blow-holes are seen, and invisible, imaginary blow-holes are not a wholly fying explanation of the fact that the pipe does not stretch

down as deep as we should expect. Finally, (4) zinc passes so suddenly from the molten to the solid state that we are loath to believe that down-sagging can have aided materially to arrest the down-growth of the pipe. Indeed, the columnar crystals (Fig. 15, I.) developed by etching give no strong evidence of any such sagging.

It was with the purpose of learning whether these four causes suffice to explain the arrest of the pipe that I requested Dr. William Campbell to prepare for me ingots of a substance which passes abruptly from liquidity to solidity, so that we could see whether in these the pipe was not thus arrested but stretched nearly to the bottom. The fact that it is thus arrested, even in this case in which it ought to stretch deep, showed me that an additional explanation was needed, and thus called my attention to the fifth of our causes, which we will now consider. I have to thank Dr. Campbell for his care in making and etching these ingots for me.

§ 28. *Cause* (5). *In the lower part of the ingot, the fact that solidification proceeds from below upwards restrains the down-stretching of the pipe.* In an ingot like III. of Fig. 15, or *B* of Fig. 22, the solidification of the lower part, as a whole, should outrun that of the upper part for three distinct reasons: first, because the lower part is poured into the mold before the upper part, so that its cooling and solidification should begin earlier than those of the upper part; second, because the lower part is narrower than the upper; and third, because the cold "stool" or bottom of the mold greatly hastens the cooling of the lower part of the ingot. As the solidification of each horizontal layer thus lags behind that of the layers beneath it, so is each layer the better able to feed down and supply the necking or gaping in the layer beneath.

It is wholly in accord with this idea that when, as in ingots *A* of Fig. 22, and I. and II. of Fig. 15, cast with the large end down, the second of these reasons is lacking, the pipe stretches far deeper than in those cast with the large end up, a matter which we will consider further in § 42. All this goes to show that the more the freezing of the upper layers lags behind that of those beneath, the more efficiently do the upper layers feed down and fill up the gaping in those beneath, and the shorter is the pipe.

Though this is true of the ingot taken as a whole, in the per part of the ingot this lag is lessened by the fact that here ich heat escapes upwards through the upper surface in addin to that which escapes laterally into the mold walls. Solidiation instead of taking place from below upwards here takes ice from above downwards. The very uppermost layers, inad of lagging behind those beneath them, outrun them; stead of feeding down to fill the gaping in the layers beath, these upper layers very often actually freeze across so as form a bridge too rigid to bend down to meet the gaping and gging beneath the crust at the top of the ingot.

At the lower end of the ingot the opposite state of affairs exs. Here the rapid escape of heat into the stool which forms bottom of the mold greatly hastens the cooling of the very ttom, making it outrun greatly that of the metal above, or, oking at it in the opposite way, greatly increases the amount which the cooling and freezing of each layer lag behind ose of the layer beneath, and thereby favors the downward ding of each layer to fill up the gap in the layer beneath. oreover, this lag becomes more and more pronounced as we t nearer and nearer to the bottom of the ingot, and the cool- effect of the bottom of the mold becomes felt more and ore. Hence, the nearer we get to the very bottom of the int, the more fluid will each layer be during the outward-draw- and gaping of the layer beneath, and the better, therefore, ould each layer fill the gaping of that beneath, and, in fine, more powerfully is the formation and down-stretching of pipe opposed.

Thus it comes about that under no conditions does the pipe er reach to the very bottom of the ingot. Even under the tremely favorable conditions of bottom-casting, to be deribed in § 40, the pipe is at least always closed at its lower d.

The effect of this downward flow of heat into the bottom of mold is clearly seen in Fig. 15, I. Here, throughout the wer 25 or 30 per cent. of the ingot's length, the inner ends the columnar crystals developed by etching point upwards, owing that the downward flow of heat had been strong enough influence their orientation greatly. Of course, a downward w of heat implies that the cooling of each layer lags behind

that of the layers beneath, because heat will flow only from a hotter to a cooler object.

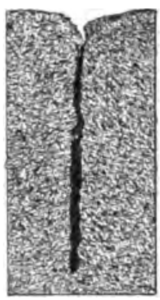
The cooling-action of the stool is much stronger than that of the walls of the mold proper, first, because the stool is usually very much thicker than the mold-walls, and second, because it is always and necessarily in firm contact with the ingot, which is pressed down upon it by gravity, whereas between the mold-walls and the ingot an empty air-space opens early in the freezing, due to the horizontal contraction of the cooling ingot and the simultaneous horizontal expansion of the rapidly-heating mold.

§ 29. *Evidence of the importance of cause* (5) is given by the results of bottom-casting, which, I believe, is the only condition under which this lag of the cooling of each horizontal layer behind that of the underlying layers is artificially prevented in the greater part of the lower end of the ingot. How it is prevented we shall see in § 40. In other words, suffice it here to point out that bottom-casting leads to concentrating the heat at the bottom of the ingot instead of at the top, so that it can be only in a very short region close to the bottom that the solidification proceeds from below upwards. Throughout nearly the whole length of the ingot it comes about that solidification progresses in the opposite fashion, from above downwards, so that each layer, instead of being in a position to feed down and fill the gaping in the layer beneath, freezes earlier than that beneath, and is thus prevented from filling up the gaping there. In short, this solidification from above downwards ought to promote the down-stretching of the pipe, by preventing cause (5) from taking effect, and this it certainly does in bottom-casting.

Thus it came about that those who practiced bottom-casting, whether they understood the reason or not, actually found that, when carried out effectively, it tended to cause an extremely deep pipe. An illustrious Pittsburg steel-maker is said to have summed this up with the remark that, after he had perfected bottom-casting so fully that his ingots piped right through from top to bottom, he abandoned it. Fig. 16 shows, on Ledebur's authority,[7] a bottom-cast ingot which has thus piped nearly to the bottom. The stumpiness of plate-ingots, together with the presence of blow-holes, may counteract this piping.

[7] *Eisenhüttenkunde*, 3d ed., vol. iii., p. 862 (1900).

0. *Summary of the five causes which arrest the down-stretch- the pipe.* Expansion in freezing, atmospheric pressure, low-holes may contribute, with varying degrees of effect cial cases, to aid the arrest of the down-stretching of the but neither severally nor jointly do they suffice to ex- its arrest in cases like that shown in Fig. 15, I and II. he down-sagging of the molten and pasty metal, and in wer part of the ingot the progress of solidification from upwards, or, in other words, the lag of the cooling of layer behind that of the underlying layers, are causes not only are at work in nearly all cases, em competent in all cases to explain this , especially in view of the fact that when, bottom-casting, this progress is from downwards throughout nearly the whole of the ingot, then, and so far as I know, nly, may the pipe stretch nearly to the a.



Taken from Ledebur, *Eisenhüttenkunde*, vol. iii., p. 862, 1900.

FIG. 16.—VERY DEEP PIPING, SUCH AS MAY RESULT FROM BOTTOM-CASTING OR VERY RAPID CASTING.

considering these cases, we should re- er that the pipe probably stretches down the point at which our section finds it, se the lower end of the pipe is very v, and may not be quite continuous, and ical section through an ingot, first, may appen to pass through the very lowest f the pipe, and, second, if it does, it is to obliterate this lower part. For in g the ingot open we have to use not a matical plane but a cutting-tool of some appreciable ess; and this tool may easily obliterate all traces of those of the pipe which are narrower than the thickness of the self.

1. *How ought sagging to affect the shape of the pipe?* In our etch of the formation of the pipe, Fig. 1, for simplicity sentation we ignored sagging, and, indeed, the important at the metal remains soft, pasty and flowing for a con- ble range below the point at which freezing begins. Let v see how the ideas which we there formed are to be ed by these facts.

us assume that at an early stage in the ebb of the molten

lake, the pipe has the shape *ABCD*, shown in Fig. 17. Here *BE* represents the left-hand shore or wall of the submerged part of the molten lake, or the boundary between the molten and the solid part. When the lake has ebbed to the position *FG*, shown in broken lines, the support which in the stage *ABCD* was offered to the part *BE* of the walls by the molten steel, has now been withdrawn, and therefore the metal thus left unsupported tends to flow down towards the cavity thus left, so that its upper surface sinks from its former position, *AB*, to something like *AF*. When the lake has ebbed further, to *JK*, the support which, in the second stage, the walls *FH* received from the molten metal at their right, has now in turn been withdrawn, and further sagging takes place, in which both the part *FH* and the previously bared part, *AF*, should

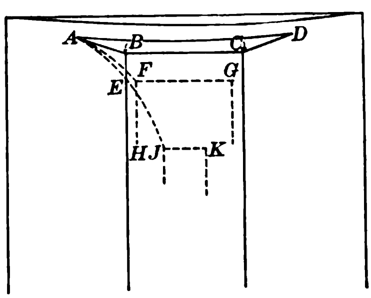


FIG. 17.—THE EBB OF THE TIDE LEAVES THE SHORES OF THE PIPE UNSUPPORTED, AND THUS LEADS TO SAGGING.

share, so that the lower side of the pipe should now have a shape something like *AEJ*.

§ 32. *How far is the pipe due to sagging rather than ebbing? Discussion.* Carrying this idea still further, step by step, we come to ask ourselves whether this sagging after solidification may not account for the whole of the pipe, and whether our first idea that it forms with the ebb of the molten lake may not be wrong. In short, may it not be that the pipe forms after even the axial layers have solidified, not by the ebb of a molten lake but by the sagging of pasty metal distinctly below its melting-point? Thus, to let the extreme case illustrate the principle, let us assume that no crevice forms within the ingot until even the axial metal has begun to freeze, and is in a mushy or pasty stage between true liquidity and effective rigidity, when it neither runs like a typical liquid nor stands firm

ike a typical solid; and that at this time a vertical crevice, *KLM*, Fig. 18, opens in the axis of the ingot, thanks to the utward drawing of the interior metal towards the outer walls. That such an initial shape is possible, the slit-like pipe in Fig. 11 shows. Would not the sagging of the pasty metal surounding this crevice, combined with the outward drawing of ts walls, change its shape through the successive stages, *NP*, *N'P'* and *N''P''* (of the first two I sketch only the upper part), o the typical pipe-shape, *QRS*?

It might, if we make one reasonable admission in order to neet a difficulty which at once confronts us. This difficulty is, hat if the metal in the relatively cool part between *N''* and *S* vere hot and soft enough to sag at all, in short, were so weak

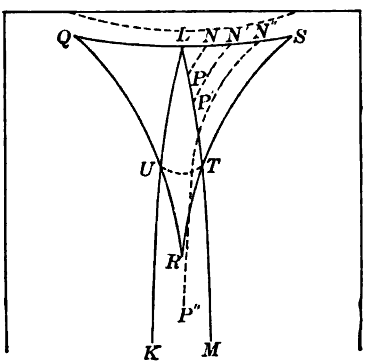


FIG. 18.—CAN THE BELL-SHAPE OF THE PIPE BE DUE WHOLLY TO SAGGING?

hat gravity sufficed to overcome its cohesion with the roof of the pipe which we suppose it to leave, then the metal in the center nd bottom of the pipe, lying as it does in the axis of the ingot, hould be so fluid that it should gather at least into a puddle vith a meniscus-shaped top, if not into a lakelet with a level op. In short, the bottom of the pipe should be level, or at east rounded, instead of being pointed, as it really is. But his difficulty is readily met. This metal which sags down to he bottom of the crevice might at first readily have an upper urface like *UT*, for of course its most liquid part, running astest and farthest, would be likely to gather beneath, and the nost sluggish of the metal, coming last, would be on top of he more liquid. Now, in the further cooling and outward

drawing of the walls, this puddle, *URT*, progressively freezing harder and harder, might readily yawn down as a crevice with nearly vertical walls.

Indeed, thus, it seems to me, we must explain the fact that the lower end of the pipe so often has nearly vertical walls. This lower vertical part, so far as I can see, must form, or at least must reach its final shape, after the metal has become distinctly solid, without any great degree of mobility; for otherwise the metal of these vertical walls would necessarily sag down to fill the lower part. For instance, all but the very upper end of the pipe in ingot *A* of Fig. 22 and in Fig. 12, must have formed after even the axial metal had reached an advanced degree of firmness. It is in accord with this idea that, so far as I have noticed, the walls of the lower vertical part are not smoothed or rounded, as if left by the ebb of a molten or even pasty lake, but ragged or crystalline, as if torn open through the solid metal, firm enough to stand thus cliff-like without sagging, yet not so rigid but that its particles can migrate into crystalline forms. This some metals can do at temperatures very far below their melting-points. Silver and copper are credibly reported to migrate into moss-form even at the atmospheric temperature.[8]

Further very strong evidence that the lower part of the pipe sometimes forms in metal which has already grown distinctly solid, is given by its sometimes stretching down far below the richest of the segregate, which is the last point to freeze. For if this, the very last freezing part, had, at the time of the opening of the lower part of the pipe, been liquid or even plastic, it would have flowed down into the chasm which thus opened beneath it; and the fact that the chasm thus yawns down below the last frozen part shows that it must have opened after the last of the freezing had ended, or, in other words, in metal which was already distinctly firm and solid.

In Fig. 13, p. 205, the width of the pipe at the level of the richest of the segregate, *g*, and the great distance to which it stretches below this level, argue powerfully that there must have been a great deal of gaping open and of downward-stretching of the pipe after even the last of the metal had acquired much firmness,

[8] Hutchings, Readwin, and Collins, *Chemical News*, vol. xxxv., pp. 117, 144, 154 (1877).

use otherwise this richest of the segregate would have run n to the bottom of the pipe, instead of staying perched up on the side of the chasm which yawned beneath it. In uring this matter in our minds, we must suppose that the est of the segregate was originally much above its present for instance at *f*, when the lower part of the pipe had a e somewhat like *cde*. Later the pipe continued to stretch n, but, for some reason hard to guess, apparently by a path ch did not pass through the richest of the segregate. As us stretched, a certain degree of sagging took place, widen- the upper part of the pipe, and carrying certain rich parts he segregate far from their initial position. Note the very spot, 0.65 carbon, near the bottom of the pipe, far below s close to the sides of the pipe with much less carbon—*e.g.*, and 0.60. That the parts which thus slid or sagged had slight mobility is indicated by the imperfect way in which closed the bottom of the pipe, leaving irregular unclosed hes at its lower end, as pellets of gradually stiffening tar ht, in sliding down such a hole. This conception helps to ain the irregular distribution of the carbon in the neighbor- l of the pipe.

he position, *g*, of the richest of the segregate, 0.70 carbon, t not be taken too confidently. Other spots lower down hich drillings were not actually taken, might, if examined, contained even more than 0.70 carbon. It is even possi- that the richest of the segregate may lie below the bottom he pipe; but in any event the irregularity with which the s richest in carbon are distributed argues strongly that h yawning open and some sagging must have taken place the segregation had very nearly completed itself, and n there was no large amount of metal that was still mobile, hen all but a very little was in an advanced stage of solidi- ion.

eturning to the question with which this section opened, e it may be possible that the pipe should begin to form, before, but after even the axial region has begun freezing, evidence as is before us indicates that much of it usually s while the metal is extremely fluid, and as sketched in 1. Some of the evidence we will now consider.

33. *Evidence furnished by the bridges.* Valuable light on this

question is given by the bridges which sometimes stretch across the upper part of the pipe in steel ingots, and even more characteristically in those of certain slags. Figs. 19 *A* and 19 *B* show a fragment in my collection from the upper part of the pipe in a potful of a ferrous silicate slag from smelting roasted cupreous pyrites. Here we note a series of three distinct bridges, each nearly level, and each smooth on top, but covered with a beautiful growth of crystals on its lower side. This

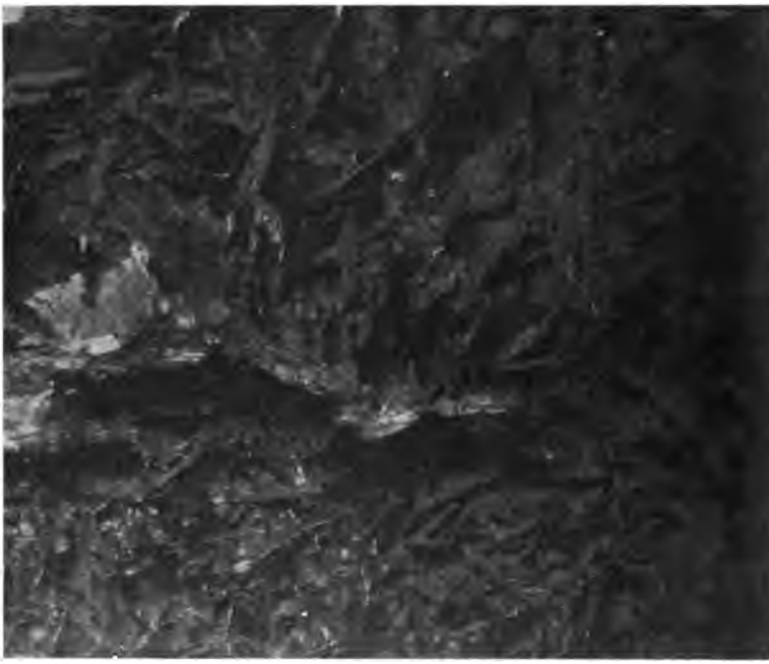


FIG. 19 *A*.—CRYSTALS ON THE LOWER SIDE OF A BRIDGE IN AN INGOT OF FERROUS SILICATE SLAG.

is just the condition which we find in the bridges in steel ingots; their upper surface is smooth, but their lower surface is covered with fine pine-tree crystals. Professor Stoughton and I found the same condition in our wax ingots.

The smooth, continuous, level upper surface of such a bridge is good evidence that this surface, when it formed, was for the moment the surface of the molten lake; and the horizontal width of this bridge represents the width of the upper surface of the lake when it was at this same level. That this bridge

formed indicates that, for some reason which we need not stop to consider, perhaps because of some phenomenon of fusion, the ebb of the lake has been arrested long enough allow its upper surface, which is radiating heat upwards oss the empty space above it to the very top crust of the in-, and therefore cooling comparatively fast, to freeze across. h an arrest could easily be caused by the formation of a ring blow-holes, beginning when the level of the lake had fallen where we now find the bridge (see § 24). Each bridge seems orm quite as the top crust of the ingot forms, by the freez- of the level surface of a molten lake.

19 *B*.—Three Level Bridges from an Ingot of Ferrous Silicate Slag.

he relatively rigid slag bridges, such as are shown in Fig. B, preserve their original evenness; they remain smooth and l; yet the bridges in a steel ingot often sag. But then this ging is only natural, and is like the sagging of the top crust he ingot. We know with absolute certainty that this latter ns by the freezing across of the upper surface of a molten ; its sagging is only the natural behavior of this metal, ch remains soft and plastic for a considerable range below freezing-point, so that, as the lake beneath it ebbs, gravity ds down the originally level bridge which this ebb leaves upported.

t is quite in conformity with this picture that often the bridge

in steel ingots is torn away from one of the sides of the pipe, and, thus left unsupported at that end, sags down there by its own weight. This is the case with the right-hand end of the bridge in the ingot from which E of Fig. 1 has been sketched, and it means that in their outward drawing the inner walls of the ingot have stretched the bridge until it broke away from one of its bearings. That it should thus break is readily understood, because, spanning as it does the chasm above the surface of the lake, its cooling outruns that of the remainder of the ingot in its neighborhood; for through the empty space

Fig. 20.—A Bridge in the Pipe in a Steel Ingot, Broken Away from Its Supports.

above it the bridge radiates heat rapidly to the thin cool upper crust of the ingot. Cooling faster, and therefore contracting faster, than the neighboring metal, it breaks away from one of its bearings, as a guitar string snaps when stretched too tight.

In an ingot which has been broken open forcibly by severe blows, I have sometimes found that the bridge has broken completely away from the sides of the pipe, and lies within it as a detached disk. In Fig. 20 the bridge is seen to be almost completely detached. Of course, the severe shock which such an ingot undergoes when it is broken open may well increase the degree to which the bridge is detached.

he beginning of the formation of such a bridge is shown at A in Fig. 21; and between the main cavity and the top are seen two distinct bridges. In our wax ingots Profes- Stoughton and I found a very great number of these ges, one above another.

34. *Evidence given by the lower side of the bridges.* The con- n of the under side of the bridge, not less than the exist- of the bridge, tends to show that it formed the upper crust h had frozen across the top of the molten lake when it had

1.—Stalactites on the Lower Side of a Bridge in a Steel Ingot.

d to this level. The stalactites hanging from beneath the bridge in Fig. 21 have evidently been left by the sinking of the molten lake which once wetted the under side of bridge, and therefore was spanned over by it.

e crystals which more often crust the lower side of the ge evidently have formed in the molten metal in contact its under side, and have been left exposed by the ebb of metal, or, as in case of Fig. 19, of that slag. We natur- ask how it comes that these beautifully fine crystalline

faces, sometimes with pine-tree growths as fine as hairs, are thus clear and sharp cut instead of being rounded like stalactites, for example, like those in Fig. 21. If, for instance, we were to dip the crystal-faced bridge of Fig. 19 *A* into a bath of slag and remove it, and allow that molten slag to drip off, or if we were to dip it in water, withdraw it, and immediately expose it to a temperature below 0°C., those exquisite crystalline facings would be smoothed over and obliterated by the frozen remains of the once-liquid bath into which we thus dipped them; for this liquid could not drip off so fully as to leave the crystalline faces clean.

The answer is, that as the ebb leaves a given very small layer bare and wet with the drip of the ebb itself, that drip is forced by the nascent crystal on which it is left into crystalline unity with that crystal. The molecules of the drip are polarized by the crystalline force into adopting the shape of the crystal itself and merging themselves in that crystalline growth, quite as when a crystal grows within a quiescent mother-liquor, this same crystalline force dragoons the molecules of the liquid in contact with the growing crystal to identify themselves with that crystal and form part of its growth.[9]

But the fineness and sharpness of the pine-tree crystals which incrust the lower side of the bridge, and the distance to

[9] I must confess that, although this explanation is on the whole satisfying, yet it leaves a slight difficulty yet unexplained. When the crystal grows in the mother-liquor it grows by selection. Quite as the plant selects from the earth that which it needs and rejects that which it needs not, so does the growing crystal select from the mother-liquor the matter which is like to itself and rejects into that mother-liquor the unlike matter. In short, this growth is by selection and rejection. But when the ebb leaves on the lowest projecting point of a downward-reaching promontory-like crystal a last drop of molten mother-slag, this drop should be parted by the crystal on and into which it grows into two parts: matter like the crystal itself, which is selected and merges with the crystal, and matter which is unlike and is rejected. But what has become of this rejected matter? We do not find it on the lower edge of the crystal, which is as sharp and sometimes as thin as a sheet of note paper. It cannot have fallen off without leaving a residual droplet; but none such is found. Does this not mean that the crystal has the power to force into its own shape and growth the last particle of mother-slag or mother-metal, even though this differs slightly in composition from the crystal itself? Does it not also mean that those relatively rare cases in which sharp, clear-cut crystals line a cavity or vug, are just those in which the mother-liquor does differ so slightly in crystalline behavior from the crystals which form within it, that those crystals are able to force the drip thus left to form part of their growth?

which they sometimes shoot out into the space beneath, show that that tide, the ebb of which has left them bare, must have been very liquid. The down-sagging of a pasty magma could hardly have left these forms so clear, so sharp, and especially so far outstretching into the void. This applies with great force to the large ill-shaped crystals which are sometimes found on the walls of the pipe beneath the bridge. It is hard to resist the conviction that the ebb which left these bare must have been of a decidedly mobile liquid, not of a barely viscous solid.

§ 35. *Evidence given by the surface of the pipe.* The general smoothness of the surface of the upper part of the pipe, even when it is furrowed as shown in Fig. 14, is that of a surface left bare by the ebb of a molten or at least of a very mobile lake. Such smoothness could hardly result from tearing open a crevice in a solid which has any considerable firmness; but it is what we should naturally expect from the ebb of a molten lake, especially when we remember that the very edges of the lake are at the freezing-point, and that while it is ebbing its layers next its shores are freezing.

§ 36. *Summary.* To sum this up: if the pipe is prolonged downwards with very steep, cliff-like, nearly parallel walls, this part seems, by its steepness and the sharp-pointing of its lower end, to have been opened after even the axial metal here has become so distinctly solid that it could not flow down to fill this crevice. But the relative flatness, the bell-shape of the upper part of the pipe itself, the smoothness and levelness of the upper side of the bridges, the sharpness of the crystals which sometimes incrust their lower side, the far out-shooting of crystals beneath them into the pipe itself, and the smoothness of the upper part of the pipe-walls, as contrasted with the crystalline mossiness of the steep lower walls, seem to show irresistibly that this upper part is opened early during the freezing, when the metal which it replaces is distinctly molten. After this upper part is thus opened, it may be further widened by the outward drawing of its shores towards the outer crust of the ingot to which they are welded.

§ 37. *How to shorten the pipe.* It is very important to shorten the pipe as much as we can, so that that part of the ingot which has to be rejected because it contains the pipe may be as short as practicable. As we saw in § 21, there is the strug-

gle between the pipe-forming or gaping tendency in the axis of each layer, due to the outward drawing of the metal towards the outer walls, which in turn is due to the virtual expansion of those walls, and the pipe-closing or sagging tendency, reinforced by the growth of blow-holes. The depth to which the pipe reaches depends upon the relation between these two tendencies, the outward-drawing, gaping or pipe-forming tendency, and the down-sagging or pipe-closing tendency. We may shorten the pipe by lessening the pipe-forming tendency, or by increasing the pipe-closing tendency, or both. Let us consider these two methods separately.

§ 38. *Shortening the pipe by lessening the virtual expansion of the crust.* If the cooling of all parts could proceed at exactly the same rate, so that the several concentric layers contracted at the same rate, clearly no pipe would arise, and the outer layers, like all the others, would, at the end of the cooling, reach exactly their natural dimensions. It is because of the early virtual expansion of the outer walls that the inner layers later draw outwards towards those outer walls, that the gaping or pipe-forming tendency arises in each successive layer, and that, at the end of the freezing, the interior does not suffice to fill the virtually expanded outer walls, and, in short, that the pipe forms. The volume of the pipe should represent the amount of this virtual expansion, and the greater this virtual expansion the greater should be the pipe. If, for instance, at the moment when the outer walls have cooled to temperature *f* in Fig. 10, p. 200, the metal within them is still so hot and expanded as to occupy volume *e*, then the outer walls are virtually expanded by an amount corresponding to the vertical distance between *f* and *e*. In short, the more the contraction of the interior lags behind that of the outer walls, or, to put it conversely, the more the cooling of the outer walls outruns that of the interior, the greater will be the virtual expansion of those outer walls, and the greater consequently will be the pipe.

Now what causes the outer walls to outrun the interior in cooling is the rapid removal of their heat by and through the mold-walls. If the mold-walls are thick, and the ingot relatively narrow, they abstract heat from the outer shell of the ingot much faster than that heat can be replaced from the interior of the ingot; so that the degree of outrunning is very

great, the outward drawing tendency and its consequence, the gaping or pipe-forming tendency, are great, and the pipe occupies a large proportion of the volume of the ingot. If, keeping the mold-walls of the same thickness, we make the ingot much wider, then the heat abstracted by the mold is quickly replaced by that which works outwards from the interior of the ingot; the mold becomes heated rapidly, and therefore abstracts further heat from the ingot but slowly. The outer shell of the ingot consequently cools relatively slowly, and its cooling outruns that of the interior relatively little, so that there is but little virtual expansion, followed by little outward drawing, little gaping tendency, and consequently but little pipe.

This agrees with the observed facts that the pipe runs very deep in narrow ingots, such as that shown in Fig. 12, p. 202; that it is large in materials which, like manganese steel, conduct heat very slowly, so that the heat abstracted from the shell of the ingot by the mold-walls is replaced only very slowly from within; that, consequently, it is very small in metals which, like copper, conduct heat rapidly; and that the pipe is shortened by the use of sand-lined molds, and still more by that of preheated sand-lined molds. It agrees also with the fact that, in narrow steel ingots, such as are made from one or two cruciblefuls in the crucible process (the common one-pot and two-pot ingots), there is rarely a solid crust above the pipe, which is open at the top, as in the zinc ingots of Fig. 15;[10] whereas in larger ingots, no matter by what process the steel is made, there is usually a solid crust or bridge across the top of the pipe. In case of narrow ingots the relatively thick mold-walls remove the heat so very quickly, and hence the pipeless period of virtual expansion is passed through so quickly and is succeeded so soon by the piping period, that this begins and makes the molten interior sink down before the cooling-effect of the air has had time to freeze the upper surface across; whereas in large ingots the sinking of the upper surface of the molten steel is delayed long enough to permit this surface to freeze across. (See §§ 5, 14.)

So, too, experiments in my laboratory showed that ingots of copper containing 4 per cent. of silver when cooled suddenly

[10] William Metcalf, Esq., private communication, May 12, 1906.

piped very deeply, but when cooled slowly formed no important pipe;[11] and that ingots of wax piped much more deeply when cooled suddenly than when cooled slowly.[12]

To sum this up, the pipe may be lessened and shortened:

(1) By casting in wide instead of narrow ingots, and

(2) By casting in sand- or clay-lined molds, especially if these are pre-heated.

§ 39. *Shortening the pipe by increasing the down-sagging pipe-closing tendency.* The preceding sections, and especially § 21, should make it clear that the down-sagging pipe-closing tendency is strengthened by retarding the cooling and solidification of the upper part of the ingot, making these lag behind those of the lower part as much as practicable, in order that, as each layer in cooling from the freezing-point down tends to gape, the overlying metal may be as soft and flowing as practicable, so that it may be forced readily by gravity to sag down and meet this gaping tendency. The more the cooling and stiffening of the upper part lag behind those of the lower, the higher up will lie that layer, the gaping tendency of which is not fully met by the downflow and sagging of the next higher layer; *i.e.*, the higher up will lie the layer in which lies the bottom of the pipe: or, in brief, the shorter will be the pipe.

As we shall see in § 51, p. 241, another beneficial effect of increasing the lagging of the cooling of the upper part of the ingot is to raise the segregation towards the top of the ingot, and thus to lessen the quantity of metal which must be cropped off in order to remove the harmfully segregated part.

This lagging of the cooling of the upper part may be increased:

(3) By top-casting;

(4) By slow casting;

(5) By casting with the large end up; and

(6) By keeping the top hot by means of a sinking-head or an equivalent device.

(A) Segregation further aids in making the cooling of the top lag, and (B) the lagging and downward-feeding are much more efficient in wide than in narrow ingots. We will now consider these six matters in series, and in §§ 48 and 49 we

[11] Experiments by Dr. E. F. Kern and R. C. Blanchard under my direction.

[12] Experiments by Prof. B. Stoughton and myself, to be described soon.

will briefly consider lessening the pipe by favoring the formation of blow-holes.

§ 40. *Top-casting* is pouring the steel in through the top of the ingot-mold, as distinguished from bottom-casting, or introducing it through a relatively small hole in the bottom of the mold. Whether the pouring is from top or bottom, at the moment when the pouring ceases the bottom of the mold must be hotter than the top, because the bottom of the mold will necessarily have been in contact with molten steel from the beginning to the end of the pouring, whereas the top of the mold does not have that contact until the end of the pouring. So far, then, top-casting and bottom-casting stand on the same footing. But, beyond this, top-pouring favors the concentration of the heat at the top of the ingot, bottom-pouring favors its concentration at the bottom. While pouring the lower part, say the lower quarter of the ingot, the difference in conditions between top- and bottom-pouring is not so very great, because in either case the metal now at the bottom of the mold is pretty thoroughly mixed up by the incoming stream, whether this is falling from the top of the mold or gushing up through its bottom. But henceforth there is a difference, which grows greater and greater as the pouring continues; and this difference is (1) that in bottom-pouring it is the bottom of the mold and ingot that is heated directly by the fresh lots of steel hot from the casting-ladle, whereas in top-casting it is the upper part that is thus chiefly heated; and (2) that in bottom-casting the steel which reaches the top of the mold has been materially cooled off in its upward journey, in which it has transferred much of its heat to the lower part of the mold-walls, and the steel at the bottom is that last added hot from the ladle, whereas in top-casting there has been no such transfer of heat from the steel now at the top of the ingot to the lower part of the mold, and the hottest steel fresh from the ladle is at the top.

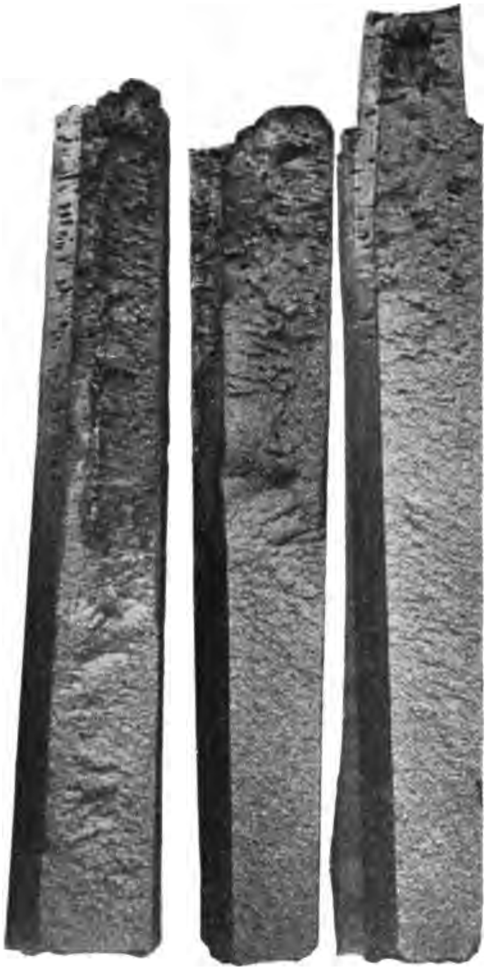
This difference increases in importance as the pouring of the ingot progresses, and the steel enters more and more slowly, and consequently stays nearer and nearer to the place where it enters. Be it remembered that the steel keeps much hotter in the great mass in which it lies in the hot clay-lined ladle, under its blanket of slag, than in the molds.

The sum of this is that, at the moment when the last of the steel has been poured into the mold, in bottom-casting the fresh hot steel is at the bottom and the bottom of the mold has been specially heated, while the steel at the top has been specially cooled; in top-casting there has been no such special heating of the bottom of the mold and cooling of the top of the steel, and the fresh hot steel is at the top.

§ 41. *Slow pouring* favors the lagging of the cooling of the upper part of a top-poured ingot, by prolonging the time during which the steel for the ingot-top is kept hot in the ladle, while the steel already in the mold, and therefore to form the bottom of the ingot, is cooling off and, indeed, solidifying because of its contact with the initially cold mold and stool. Moreover, quick pouring by means of a swift and large stream of molten steel keeps the whole of the metal in the mold in such rapid motion as to efface, in large part, the cooling-off of the lower part of the ingot during the time when the upper part is pouring; but a slow stream enters the molten mass already in the mold more gently, stirs it less, and disturbs less the faster cooling of the lower part of the ingot because of its earlier entry into the mold. This distinction is of especial importance during the latter part of the pouring, when a slow stream may leave the lower part of the metal almost wholly unaffected.

This conclusion, which I reached by *a priori* reasoning, I find is borne out by experience in crucible-steel practice, in which rapid pouring increases the depth of the pipe; and Professor Stoughton and I found that narrow deep wax ingots, though they piped to within 10 per cent. of the bottom when poured very rapidly, yet formed only a very shallow pipe, reaching only to 13 per cent. of the length of the ingot, when poured very slowly.

§ 42. *Casting with the large end of the ingot up* (ingot *B* of Fig. 22) instead of down (ingot *A* of Fig. 22) clearly must increase the lag of the cooling of the upper part of the ingot, because the thicker end of the ingot cools more slowly than its thinner end, and must thus shorten the pipe and raise the segregation. In a direct test, in which steel from the same heat was cast into molds which were alike, except that the large end was up in one of them and down in the other, Mr. J. O. E. Trotz found, on



A *B* *C*

FIG. 22. —CASTING WITH THE LARGE END UPPERMOST, AND WITH A SINKING-HEAD, SHORTENS THE PIPE IN STEEL INGOTS See §§ 42 and 44.

Ingots *A* and *B* were cast simultaneously through two nozzles from the same ladleful of steel of 0.50 per cent. of carbon, into molds 54 in. long, 6.75 in. square at the small end and 8.75 in. square at the large end, and in every respect alike, except that the large end was at the bottom in case of ingot *A* and at the top in case of ingot *B*. The pipe could be traced to a depth of 75 per cent. of the length of ingot *A*, or much further than is shown in this figure. Ingot *C* was cast with a sinking-head, a fire-brick sleeve around the contracted part at its top. (J. O. E. Trotz, Esq., private communication.)

breaking the resulting ingots across transversely, that the pipe stretched down less than 21 per cent. of the length of the ingot

with its large end up, but more than 73 per cent. of that with its large end down. The molds were 64 in. long, 6.75 in. square at the small end, and 8.75 in. square at the other.

In another direct test he cast steel of 0.50 per cent. of carbon, from the same ladle, simultaneously through two nozzles into the ingots shown at *A* and *B* of Fig. 22, in molds which, as before, were alike except that the large end of one was up and that of the other down. The pipe, which in *B* is only rudimentary, in *A* could be traced to a depth of 75 per cent. of the length of the ingot. The illustration does not show the full

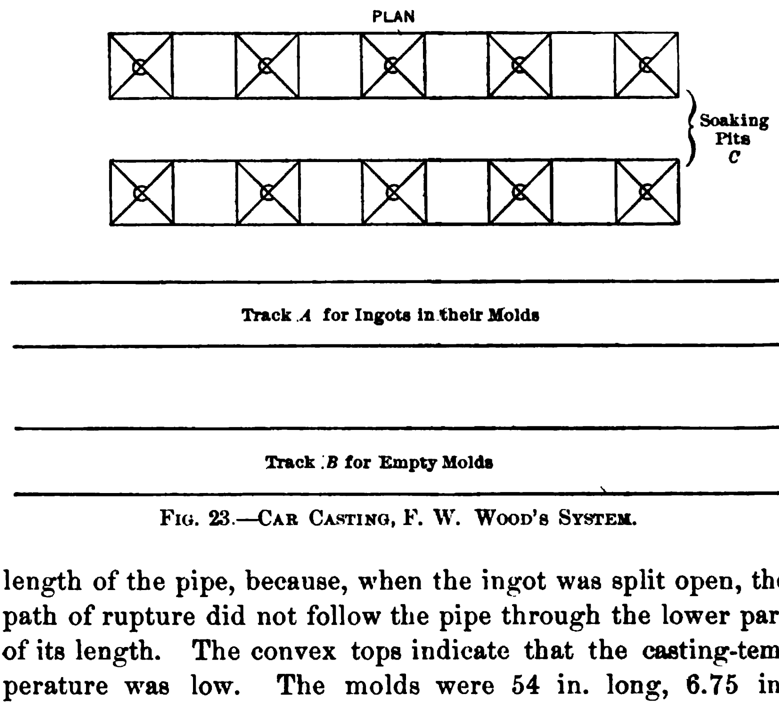


FIG. 23.—CAR CASTING, F. W. WOOD'S SYSTEM.

length of the pipe, because, when the ingot was split open, the path of rupture did not follow the pipe through the lower part of its length. The convex tops indicate that the casting-temperature was low. The molds were 54 in. long, 6.75 in. square at the small end, and 8.75 in. square at the other.

Again, Professor Stoughton and I found that strongly tapered wax ingots with the large end down piped very much deeper than exactly like ingots cast with the large end up.

§ 43. *Administrative aspect of casting with the large end up.* It is true that casting with the large end down has a certain advantage from an administrative point of view, because from an

ingot so cast the mold can be removed more readily with the means now in use than from one of which the large end is uppermost. Indeed, our large American works have been planned for casting with the large end down. The ingots are cast in molds which stand upon cars, and, without waiting for the steel to solidify, a train of these cars is carried to track A, Fig. 23, beside the soaking-pits. Here the molds are lifted from the ingots and placed on another set of stools standing on cars on track B. The ingots which have thus been left bare, standing on their stools on the cars on track A, are next lifted

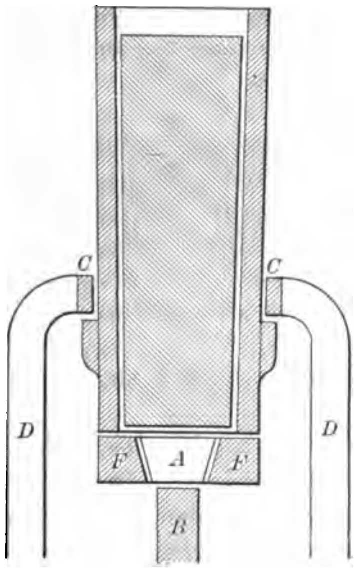


FIG. 24.—PROPOSED STRIPPING SYSTEM, MOVABLE STOOL-PLUG.

into the soaking-pits, C, C. Thus, a single moving of the molds and a single moving of the ingots puts the latter into the soaking-pits, and the former upon a fresh set of stools, ready, as soon as they are cool enough, to receive a fresh lot of steel.

But the advantage of this simplicity of administration may prove to be outweighed by the disadvantage which is inherent in this system, the disadvantage of making the pipe deeper-reaching and the segregation deeper-seated than they would be if the large end were uppermost.

Two ways of stripping ingots cast with their large end uppermost have suggested themselves to me, and still better ones may occur to others. The first is to have a movable tapered stopper, *A*, conical or pyramidal, in the stool of each mold, as shown in Figs. 24 and 25. When the train of full molds has come beside the soaking-pits, the ingot is raised out of its mold by pushing up this conical piece by means of a ram, *B*, from below. The protruding ingot is then grasped by a pair of tongs from above and transferred into the soaking-pit, while the mold is left standing on its stool and on its car, ready to receive a fresh lot of steel as soon as it has cooled sufficiently. This way is, in one sense, even simpler than the present way indicated in Fig. 23, because the molds do not have to be

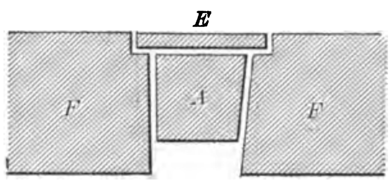


FIG. 25.—CAR CASTING, MOVABLE STOOL-PLUG, LARGE SCALE.

moved at all. There is only a single moving, that of the ingot.

If the molds were used too long or too hot, so that the ingot stuck to them instead of rising freely within them, they would have to be held down, for instance either by horizontal fixed bars, *C*, held by posts, *D*, or else by a piece projecting down from the crane which is to lift the ingot.

The natural objection which one raises to such a plan is that the steel may run down through the crevice between the stopper, *A*, and the rest of the stool. Though there is no clear reason why the steel should run through this crevice more readily than through that between mold and stool, yet if it did it would be likely to grip the stopper, *A*, so that it would not fall back with the plunger, *B*, when this was later lowered. Should it prove that this was really likely to happen, then a heavy plate-steel or even cast-iron cover, *E*, Fig. 25, could be set upon the stopper, *A*, with a layer of clay-wash between

them, which ought to arrest any molten steel which worked into the crevice between *E* and *F*.[13]

The second way which I propose of stripping ingots cast with the large end up is sketched in Fig. 26. Here the full molds are lifted from their stools and set upon the stripping-stand, *G*. Then a plunger from beneath pushes each ingot up through its mold, which, meanwhile, is held down, either by a clamp or by a projection from the crane above. This crane carries tongs, which grasp the emerging ingot and transfer it at once to the soaking-pit. The empty mold is then returned to its stool on the car still standing beside it on track *A*.

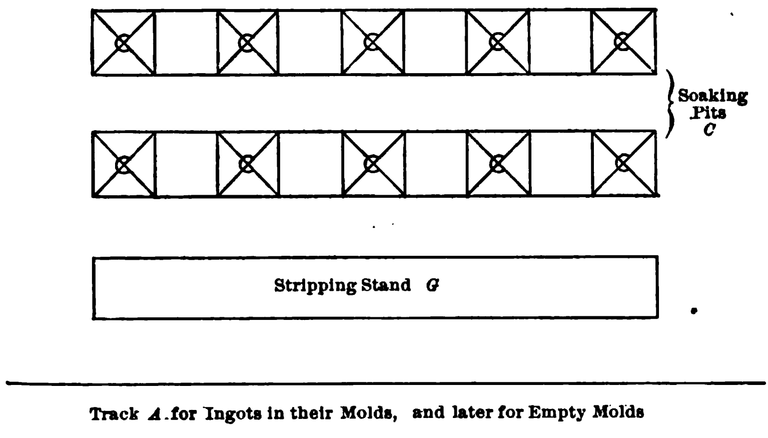


FIG. 26.—CAR CASTING, TWO MOVEMENTS FOR MOLD.

The disadvantage of this method is that it involves an additional moving for the mold. This has to be moved first from its car to the stripping-stand, and then from the stripping-stand back to its stool. But the cost of this additional moving may be outweighed by any material reduction in the needed length of cropping, or any material lessening of the segregation, brought about by having the large end uppermost.

§ 44. *The use of a sinking-head* or any other device for retard-

[13] When I wrote this, I thought that my invention was new. But, on inquiry, I find that Messrs. John A. Potter and William H. Morse have separately and independently invented this same contrivance. (See U. S. Patents, No. 601,083, March 22, 1898, and No. 735,795, August 11, 1903.)

ing the cooling of the top of the ingot, and for feeding molten metal into the pipe as it forms, evidently should favor the lagging of the solidification of the ingot-top. Prominent among such methods is that of making the upper section of the mold, that part which contains the tapered top of the ingot, shown in Fig. 22, *C*, p. 227, of a fire-brick piece, a continuation of the usual cast-iron mold which serves to hold the rest of the ingot. This fire-brick prolongation is strongly pre-heated, and set in place just as the steel is to be cast in the mold. Other methods are to keep the ingot-top hot by means of a gas-flame (Riemer's process), a coke fire, or a large mass of molten slag poured into the upper part of the mold.

Closely related to this is the regular practice of many crucible-steel works in casting large ingots, and, indeed, all ingots large enough to need several cruciblefuls of steel. In this practice a few specially hot cruciblefuls are held in reserve in the furnace until the ingot-mold is nearly full, and then they are poured into it last, in order to raise the temperature of the top of the ingot relatively to the rest of it. If this practice is followed the pipe is short; whereas, if the cruciblefuls which are to form the top of the ingot are drawn from the furnace needlessly early and carelessly left standing on the floor, so that they cool off materially, the pipe may stretch down much deeper.[14]

The cooling of the bottom of the ingot is hastened spontaneously by the cooling effect of the thick cold cast-iron stool which forms the bottom of the mold. From the middle of the length of the ingot heat escapes only outwards; at its bottom heat escapes both outwards and downwards.

§ 45. *Segregation increases the lagging of the cooling of the upper part of the ingot.* The segregation which occurs in the freezing of a steel ingot is due to the fact that its freezing is selective—*i.e.*, that each layer of the molten steel in the act of freezing breaks up into two parts, a less fusible part which actually freezes, and a more fusible part which remains unfrozen, as part of the still molten central lake. Thus, in effect, each layer as it freezes ejects into this lake some of its more fusible matter, especially its carbon, phosphorus, and sulphur, and this

[14] William Metcalf, private communication, May 12, 1906.

leads to a progressive concentration of these impurities in the molten lake and eventually in its last remaining drops, the last-freezing part of the ingot, which thus is the richest of the segregation. That is to say, at a given instant during freezing a single layer of nearly uniform composition should be deposited on the bottom and on all sides of the molten lake; and as segregation and the consequent enrichment of the molten lake take place progressively, and as the richer the lake the richer should be the layer which freezes out of it, so each layer deposited should be slightly richer than the preceding, and these successive layers should thus lie, onion-wise, around the last-frozen and most-segregated spot.

§ 45 A. *Lightness of the segregated matter.* Each layer as it starts to freeze along the shores and bottom of the molten lake may, for simplicity, be assumed to have the average composition of the molten lake which deposits it. But, as the part of this layer which does not freeze but is rejected and injected into the molten lake, is richer in carbon, phosphorus and sulphur than the average of the layer itself, it is richer also than the lake into which it is thus injected. Further, because the carbides, phosphides and sulphides of iron are lighter than iron itself, this injected matter should be lighter than the average of the lake into which it is injected. Thus there forms around the deep shores of the lake a layer lighter than the rest of the lake, and this should lead to a slow upward current around its shores, and a downward current about its axis, and thus these impurities should be concentrated upwards. But, as these impurities make the metal more fusible, this migration should make the upper part of the molten lake more fusible than its lower part, and this should retard the freezing of the upper part of the ingot.

There is another thing which may reinforce this tendency. If steel behaves like most substances and contracts as it cools towards the freezing-point, then the hottest of the molten metal would be the lightest, and the coolest would be the heaviest, and this natural difference in density would make the hottest metal rise towards the top and the coolest sink towards the bottom, thus further concentrating the heat at the top of the ingot, and thus further retarding the freezing of the top. In

short, both the more impure and hence the lighter and the more fusible of the steel, and the hotter of the steel, should migrate towards the top, which would therefore freeze more slowly than the bottom, both because more fusible and because hotter.

Further, this upward concentration of the hotter and more fusible steel should be progressive, so that the imaginary central point about which the freezing takes place in concentric layers, instead of being fixed, should rise slowly as freezing itself proceeds.

§ 46. *The high position of the segregate tends to show that steel does not expand in cooling towards the freezing-point.* By reversing our process of reasoning, we find here evidence that molten steel does not, like water, expand as it nears the freezing-point. The fact that water thus expands, as shown in Fig. 27, explains easily why the segregate in ice ingots lies below the center, instead of above, as in the case of ingots of steel. To simplify our ideas, let us suppose that, in the central unfrozen lake of a freezing ice ingot, all the water was between 4° and 0°, or between *a* and *b* of Fig. 27. In this case the coldest of the water is the lightest and rises to the top, while the least cold is the heaviest and sinks to the bottom, and this hastens the cooling of the top and retards that of the bottom, and thus lowers the position of the last-freezing point or richest of the segregate. A further cause which makes in this same direction is that the impurities in the freezing water, which are rejected by the freezing layers and thus injected into the still unfrozen water, are chiefly mineral salts, which are both more fusible—*i.e.*, have a lower freezing-point—and heavier than the water, and therefore sink towards the bottom. These causes concentrate at the bottom of the freezing ice ingot both the warmer and the more fusible part, and thus in both ways retard the freezing of the bottom. Thus it is that I explain President Drown's observation[15] that the richest of the segregation in ice ingots is found below the center, a fact which seems to have puzzled even this acute reasoner.

Now, applying these facts to the case of freezing steel, if the steel expanded, as sketched in Fig. 10, p. 200, as it cools through

[15] *Journal of the New England Water Works Association*, vol. viii., p. 50 (1893).

the last few degrees above the freezing-point, then the hottest of the molten steel should be the heaviest and should sink towards the bottom, while the least hot should be the lightest and should swim to the top of the molten lake; and this should retard the freezing of the lower part of the ingot and hasten that of the upper part, so that the last part to freeze would be below the center, or, in fine, that the richest of the segregate would be below the center.

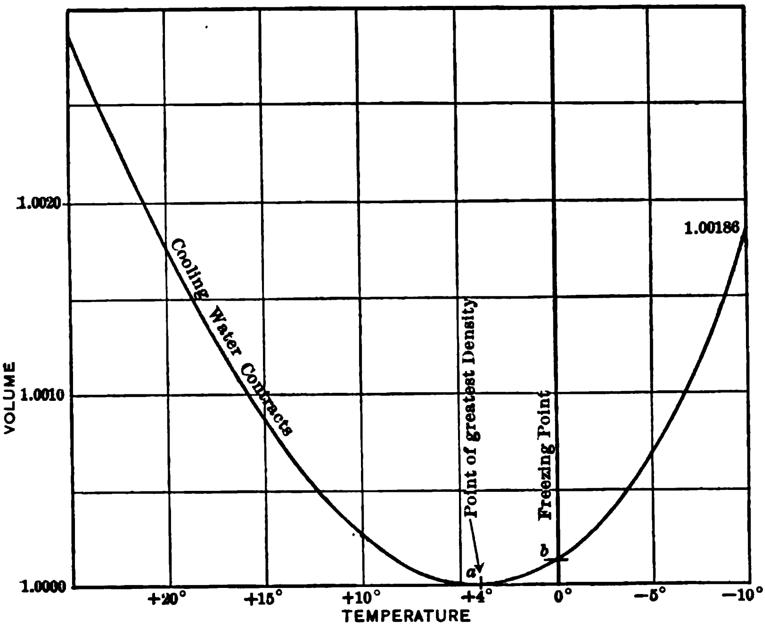


FIG. 27.—WATER EXPANDS IN COOLING FROM 4° C. DOWNWARDS.

But in point of fact the richest of the segregate is always found above the center, and generally very far above it, even when the other conditions of the case tend to bring it below the center. I refer to such conditions as having the larger end of the ingot below instead of above, and cooling the top of the ingot with water.

When this line of reasoning first occurred to me it seemed attractive. But on further examination it lacks cogency. For, on the hypothesis that cooling steel, like water, does expand in approaching the freezing-point, though it is true that the hottest of the steel would sink and the coolest rise, yet this might

not prevent the rise of the impurities rejected by each successive freezing layer; so that there may be two simultaneous and opposite concentrations going on, that of the hotter and heavier steel downwards and of the more impure and lighter steel upwards. This might even go so far that the richest of the segregate should not be the last-freezing point; because as the impurities swim up and the hotter steel dives down, the richest of the segregate may lie well above the middle of the ingot, though the hottest point lies well below that middle; and the richest of the segregate may be so much cooler than the hottest point that it freezes first in spite of it being made more fusible by its very impurity.

But, though not conclusive, this fact that the richest of the segregate invariably lies well above the middle of the ingot is certainly strongly suggestive, and, as far as it goes, it strengthens the presumption against the hypothesis that molten steel expands as it nears the freezing-point. Of course, it throws no light whatsoever on the further question, whether steel expands in the very act of freezing and in cooling below the freezing-point.

§ 47. *Liquid compression.* That compressing the steel while it is solidifying—*i. e.*, while the pipe is forming—should tend to lessen this pipe by forcing the molten and pasty interior into it as it forms, or, indeed, after it has formed, needs here to be mentioned only. In §§ 60 to 71 we shall ask how liquid compression may be made most effective, both for raising the segregate and for closing the pipe.

§ 48. *The formation of blow-holes*, as we saw in § 24, lessens the pipe, and on this account the steel-maker habitually permits them to form, but in such small quantity and in such a position that they shall not harm the steel materially. Given a normally low casting-temperature, normal freedom from gas brought about by sufficiently boiling the metal after the last addition of ore, and a normal slag, the quantity and position of the blow-holes may be regulated by the additions of silicon, manganese, and aluminum made just before teeming, whether in the furnace or in the casting-ladle. These additions severally and jointly lessen the blow-holes; they should be added in such amount as to permit the formation of a small quantity of deep-seated blow-holes. For instance, under the special conditions

of Brinell's well-known experiments, if the sum of the percentage of manganese plus 5.2 times the percentage of silicon is as much as 2.05 per cent., the steel will be so free from blow-holes that it will pipe badly. If this sum is reduced to 1.66 per cent., there will be just that small quantity of hardly visible blow-holes which will nearly efface the pipe. But if this sum is between 1.16 and 0.50 per cent., the blow-holes are so large as to be harmful, and they cannot be effaced by welding, because they lie so near the skin of the ingot that their walls are oxidized by the infiltering atmospheric oxygen, so that the contact of metal with metal, necessary to welding, is lacking. But, finally, if this sum is as small as 0.28 per cent., the blow-holes which form are so deep-seated as to be harmless, because their sides will not be oxidized, and therefore they will weld up completely in rolling, and will thus disappear.

If 0.0184 per cent. of aluminum is added, the effect is the same as if the sum of the percentage of manganese added plus 5.2 times that of the silicon were 1.66 per cent., so that here 0.011 per cent. of aluminum is the equivalent of 1.00 per cent. of this sum of Mn + 5.2 Si.[16]

§ 49. *The blow-hole forming period.* As when, in drawing from a soda-water siphon, we thereby reduce the pressure, so that the water, becoming supersaturated, evolves its excess of gas, and gas-bubbles form throughout the water and rise towards the surface; so, when the pressure within the ingot is reduced by the decrease in the extent to which the contraction of the outer walls outruns that of the inner walls, gas which has been dissolved by the great pressure in the already frozen but plastic inner walls is now evolved, and, unable to rise towards the surface, is yet able to push aside the surrounding steel sufficiently to coalesce into bubbles or blow-holes. Let us go on to consider this in more detail.

We have seen that during the early part of the pipeless period the contraction of the outer walls outruns that of the inner walls so greatly that each presses strongly against the other, but that this lagging of the inner walls gradually decreases, and

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[16] *Journal of the Iron and Steel Institute*, vol. lxi. (1902, No. I.), pp. 333 to 353. "Iron, Steel and Other Alloys," pp. 368, 369.

with it the pressure between inner and outer walls decreases, until finally this pressure becomes zero.

Indeed, it should turn from compression into tension. That is to say, the inner walls should henceforth be under slight tension, like the india-rubber which, in Fig. 4, p. 182, is pulled inwards by the strings. But any such tension is likely to be small, for an obvious reason. During the compression period, great compression can arise, at least in case the upper crust of the ingot freezes across firmly, because the inward pressure of the outer walls against the inner ones is resisted by the nearly incompressible molten lake against which the inner walls are compressed; but the outward drawing of the inner walls, after their rate of contraction has begun to outrun that of the outer walls, is not at all opposed by the molten metal within.

Suffice it for our present purpose to recognize clearly these two distinct periods: first, of strong compression, gradually diminishing to zero; second, of probably slight tension.

The evolution of gas depends upon the balance between existing pressure and existing solvent power for gas. If the metal contains more gas than suffices to saturate it for existing temperature and pressure—*i.e.*, if it is supersaturated—it normally evolves its excess of gas; if it contains less gas—*i.e.*, if it is not supersaturated—it does not normally evolve gas.

In general, the solvent power falls as the pressure falls; and in general it rises as the temperature falls. Thus, to heat a solid, for instance charcoal, may expel part of its dissolved gas; and a tumbler of water drawn cold from the faucet gradually evolves gas, as it stands and warms up on the sideboard. We are all familiar with the bubbles which form slowly on the sides of the glass under these conditions.[17]

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[17] Certain metallurgists contend that the solubility of gases in molten steel decreases as the temperature falls towards the freezing-point, and that in this respect molten steel differs radically from other liquids in general. They point to their observation that, when in the open-hearth furnace the charge has ceased to boil, boiling may be induced by shutting off the supply of gas altogether, which no doubt lowers the temperature. They overlook a simultaneous effect of this same cause, that of increasing the strength of the oxidizing conditions to which the upper surface of the slag is exposed, by playing upon it a stream of white hot air now unmixed with gas. This may well act by increasing the proportion of ferric to ferrous oxide in the slag, and thereby inducing that slag to oxidize the carbon still remaining in the molten metal beneath, with evolution of carbonic oxide, which indeed is what the boil really consists in. In short, it is probably

But though it is perfectly true that, as cooling proceeds, the solvent power for gas increases, yet when our cooling reaches the freezing-point this rise of solvent power abruptly turns into a rapid fall during the very act of freezing, again changing to a rise as the frozen metal cools from the freezing-point downwards.

If, to imagine an ideal case, steel cools, freezes, and then cools further, all at atmospheric pressure, as it cools from its casting-temperature towards the freezing-point the evolution of gas should slacken till the freezing-point is reached, should then become active during freezing, and should again slacken after freezing is complete, and the metal starts on its long journey of cooling from the freezing-point to the atmospheric temperature. It is true that we do not habitually see this slackening just before freezing sets in, in the steel in our molds, because as soon as we begin pouring into the mold some part of the steel actually begins to freeze, and therefore to evolve gas.

In short, if there were no change in pressure, gas should be evolved during freezing, but not while the steel is cooling from the freezing-point down.

Let us now consider how this course of events is affected by the changing pressure in our ingot, first a rise and later a fall.

The early rise of pressure, raising the solvent power of the freezing steel, lessens the quantity of gas which it evolves in freezing, and thus increases the quantity of gas stored up in the frozen steel. With the subsequent fall of pressure the solvent power, too, will fall, and in certain layers it is likely to fall by an amount which will so far exceed the simultaneous rise of solvent power, due to simultaneous fall of temperature, as to supersaturate these layers with gas, with the result that they will start to evolve the gas which they hold in excess of their present saturation-point. If those layers are so cool as to be rigid, this evolved gas must work its way outwards slowly as

through strengthening the oxidizing conditions, and not through lowering the temperature, that cutting off the gas induces a boil. We should be reluctant to assume that the common laws of nature are reversed, and should seek diligently for other explanations of any phenomena which, at the first superficial glance, seem to suggest such reversal. For examples of the great decrease of the solubility of many gases in water and other liquids as the temperature rises from 0° to or towards 100° C., see Landolt und Börnstein, *Physicalisch-chemische Tabellen*, p. 256 *et seq.* (1894).

best it can. If they are so hot as to be soft and plastic, the evolving gas will coalesce into bubbles of some size; and, indeed, into each incipient bubble gas will evolve the more freely because the surface-tension of the bubble decreases progressively as its radius increases.

§ 50. *Normal position of blow-holes.* In the cross-section of a common steel ingot, Fig. 28, we note three distinct zones: an outer one, free from blow-holes; an intermediate one, containing a ring of blow-holes; and a central one, free from blow-holes. The outer clear ring and the intermediate ring of blow-holes are strikingly seen in our common ingots of artificial ice.

The intermediate ring represents already solid metal which, at the time when the pressure is falling, is (1) so rich in gas, and so hot, and therefore with so low a solvent power for gas, that the fall of pressure suffices to supersaturate it, so that gas evolves within it; and (2) so hot and soft that this gas can push it aside and form blow-holes.

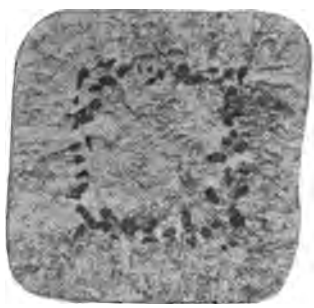

FIG. 28.—NORMAL DEEP-SEATED BLOW-HOLES IN STEEL INGOTS. Brinell.

The outer ring represents metal either too cold and rigid, at the time when the pressure is falling, thus to permit blow-holes to form, or so cool, and therefore with so great solvent power for gas, that the fall in pressure fails to supersaturate it.

The inner circle may represent metal so poor in gas, because frozen under such slight pressure, that the fall of solvent power, due to later small loss of its small initial pressure, does not outrun the simultaneous gain in solvent power due to cooling, or does not outrun it enough to supersaturate the metal with gas. Hence no gas evolves within it, and no blow-holes form. Or it may represent metal so mobile that the gas evolved within it is able to work up and out into the still molten part, to swim through this to the top of the molten lake, and to work its way out through the holes, or at least pores, which are almost certainly always present in the top crust of the ingot.

The general shape of the blow-holes of this outer ring, as shown in Fig. 22, *A*, *B* and *C*, p. 227, and Fig. 11, p. 202, seems,

on the whole, to agree better with this latter hypothesis. The side blow-holes are not horizontal, but tilted; the inner end of each blow-hole is higher than its outer end, as if it formed in more mobile metal, and thus had been able to rise slightly by gravity, though not enough to overcome surface tension and free itself from the outer end of the blow-hole. The upper end of the blow-holes along the bottom of the ingot is usually much larger than the lower end, as if formed in more mobile metal, and in many cases the shape of the bubble suggests that it is the relic of a once longer bubble, of which the upper part has detached itself and risen to the surface. In ice ingots these bubbles are usually greatly elongated, and they curve gradually upwards as if, growing with the growth of the walls, the nascent inner end of the bubble had kept rising line by line as it lengthened, ever pressing upward against the not yet rigid wall, with whose growth its own keeps pace.

That the longer axis of each blow-hole should be normal to the nearest cooling surface, or, in other words, parallel with the axis of the columnar crystals between which it forms, is most natural. Each crystal, as it grows, would naturally reject into the space between itself and its neighbors any gas which it was compelled to expel.

My purpose in giving these general considerations about blow-holes is to stimulate others both to think about their causes and to publish the results of their own observations, with the further object of helping towards the formation of a true theory of their formation and prevention, both in order that the known facts may be conveniently and clearly grouped, and also that, by means of such a theory, we may predict laws not yet known, and thus develop further knowledge of direct value. At present I confess to great difficulty in forming any theory which is consistent with all of the facts, or even with nearly all of them. One which I prepared with great care for this paper I find so defective that I have suppressed it.

II. Segregation.

§ 51. *Precautions against segregation.* Before taking up these precautions, the reader should have clearly in his mind the picture of segregation drawn in §§ 45, 45A and 46, pp. 232 to 236.

To lessen the irregularity of composition which segregation

causes, we should either restrain segregation or cut off and reject the segregate, or do both. If we are to cut it off, then we should aim to raise it—*i.e.*, to cause it to form as near the top of the ingot as possible—so as to reduce to a minimum the quantity of metal which thus has to be sacrificed.

§ 52. *In order to raise the segregate* we should retard the cooling of the upper part of the ingot, by the means described in §§ 39 to 44, pp. 224 to 232, so that the last part to solidify, which will be the richest of the segregate, shall lie as near as practicable to the top of the ingot.

These means were:[18]

(3) Top-casting;

(4) Slow-casting;

(5) Casting with the large end up, and

(6) Keeping the top hot by means of a sinking-head or other device.

The purpose immediately before us when we were there studying these devices was to shorten the pipe. But as each of these steps did this by making the cooling of the upper part of the ingot lag behind that of the lower part, and as increasing this lag must tend to raise the position of the last-freezing point or richest of the segregation, it is evident that each of these steps must tend also to raise the position of the segregate.

Two other steps which certainly shorten the pipe may raise the position of the segregate; these are:

(7) Permitting deep-seated blow-holes to form, by adjusting the quantity of silicon and manganese, or their equivalents, and

(8) Liquid compression.

In passing let us note that the steps which shorten and lessen the pipe by lessening the virtual expansion—viz.:

(1) Casting in wide instead of narrow ingots;

(2) Casting in sand- or clay-lined molds—

ought not, for any of these reasons which we have been discussing, to raise the position of the segregate, because they do not act through increasing the lag of the cooling of the upper part of the ingot. Indeed, by causing the solidification to take place slowly, these steps may prove to increase the degree of segregation.

[18] For the sake of uniformity I here retain the designation-numbers already given these several steps in the preceding parts of this paper.

§ 53. *Restraining segregation.* Turning now from the means by which the segregate may be raised towards the ingot top, without necessarily changing the degree of segregation, let us next consider the means by which segregation may be lessened, so that the metal may be more nearly homogeneous. Prominent among the means which are either known or thought to lessen segregation are these:

(9) Quieting the steel—*i.e.*, suppressing the evolution of gas during solidification, by adding aluminum or its equivalent;

(10) Casting in small instead of in large ingots.

Hastening the solidification, not only by casting in small ingots, but also

(11) By casting at as low a temperature as practicable;

(12) By casting in thick-walled cold iron molds, instead of in sand or clay molds; and

(13) by casting slowly.

Before going on to consider these means in detail, let me at once point out that, though quieting wild steel certainly seems to be a most effective way of lessening segregation, yet the effect of ingot-size and of the rate of cooling is in dispute.

§ 54. *Quieting the steel.* Mr. B. Talbot[19] has certainly made out a very good *prima facie* case for the theory that quieting the steel by additions of aluminum lessens segregation, and Mr. Stead[20] has shown clearly that it ought to do this, because this quieting, by suppressing the evolution of gas and the vio, lent upward convection-currents which this evolution sets up[1] tends to change the mode of solidification from the onion-type,[2]- in which freezing proceeds by depositing a succession of smooth concentric layers of frozen metal along the narrowing shores and walls of the submerged molten lake and thus gradually sweeping the segregate axis-wards, to the "land-locking"[22] type, in which it proceeds by sending out long pine-tree crystals, the interlacing boughs of which mechanically land-lock much of the molten metal, and thus prevent the carbon, etc., ejected from each freezing layer in these land-locked harbors and ponds from working its way by diffusion towards the central axis of the ingot.

[19] *Journal of the Iron and Steel Institute*, vol. lxviii. (1905; No. II.), pp. 204 to 223. [20] *Idem.*, pp. 224 to 228.

[21] *Iron, Steel, and Other Alloys*, the Author, p. 85. [22] *Idem.*, p. 95.

Clearly a given molecule of, say, sulphur, which is land-locked by the out-shooting crystals in the walls themselves, is thereby prevented from traveling centerwards and contributing to the central or axial segregate.

§ 55. *Influence of ingot-size.* Though it is the very general and in my opinion wholly natural belief that large ingots segregate much more than small ones, yet the remarks of such distinguished metallurgists as Messrs. H. H. Campbell and B. Talbot certainly make rather against than for that belief. A very large mass of data which I have analyzed tends so strongly to show that the prevalent belief is right—*i.e.*, that large ingots segregate more than small ones—that I adopt this belief provisionally. But this question is so important that I have undertaken further experiments and a systematic analysis of the data at hand. Postponing a full discussion till this work is done, I now offer some thoughts on this general subject.

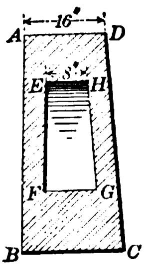

FIG. 29.—SEGREGATION SHOULD BE GREATER IN LARGE THAN IN SMALL INGOTS.

The influence of ingot-size, though it no doubt depends in part on the simultaneous influence of the rate of cooling, because large ingots naturally cool much more slowly than small ones, yet in addition depends on a second principle, which I will explain briefly.

At the time, T, when the freezing of a 16-inch ingot, *ABCD*, Fig. 29, has progressed so far that the volume of the molten lake remaining inside it is approximately that of an 8-inch ingot, *EFGH*, a great deal of segregation will already have taken place; the molten interior will now be much richer in the segregating elements than the already frozen walls. But from this time on the conditions in the further freezing of this molten lake will be pretty much the same as those in an 8-inch ingot, so that, at the end, in the 16-inch ingot there will be superadded to the segregation normal for an 8-inch ingot that which had already taken place at the time, T, when freezing had reached approximately the condition shown in Fig. 29. In short, there should be much more segregation in a large than in a small ingot.

Of course, this central 8-inch prism within our 16-inch ingot must cool very much more slowly than a common 8-inch ingot in contact with its initially cold mold. Suffice it here

to point out, that there are here two distinct influences, the direct influence of ingot-size, and the influence of the rate of cooling. If, as certainly is to be expected, the direct effect of ingot-size is to favor segregation, then, if slow cooling itself increases segregation, large ingots should segregate more than small ones for a double reason. But if slow cooling opposes segregation, then the direct effect of ingot-size is opposed by the incidental effect of the slow cooling to which large size leads.

§ 56. *Influence of the rate of cooling on segregation. Important distinctions.* Let us at once recognize that we have here to do with three really distinct though closely related things:

(1) *The multiplication of phases*, as when a homogeneous liquid in solidifying yields not one but two or more products (*e.g.*, when molten cast-iron in solidifying yields austenite plus graphite or cementite or both); or when a solid solution is transformed into two or more products (*e.g.*, austenite transforming in the eutectoid range into ferrite and cementite);

(2) *Axial segregation*, the centerward concentration of the more fusible substances; and

(3) *Local coalescing* of the particles of the different phases, such as ferrite and cementite, into larger masses.

Let us further recognize that what we are now studying is the degree of axial segregation, and not the multiplication of phases or local coalescing; the concentration of the more fusible substances around the axis of the ingot, and not the degree to which graphite or cementite forms in solidifying, nor the completeness with which austenite passes into ferrite and cementite in cooling past the eutectoid range, nor yet the size which the particles of ferrite and cementite reach through the coalescing of the extremely minute particles which result initially from the transformation of the austenite.

Let us now consider the effect of rapidity of cooling on these three things.

§ 56 A. *The multiplication of phases* is certainly opposed by rapidity of cooling. When glass is cooled at the usual relatively rapid rate, it remains apparently a single solid solution; when it is cooled slowly enough it devitrifies, or splits up into distinct mineralogical entities and loses its transparency. So in the cooling of igneous rocks and slags. A slag which is simply

a black glass when quenched in water, when cooled slowly splits up into different constituents or phases.

When molten cast-iron solidifies and tends to split up into solid austenite plus either the labile cementite or the stable graphite, it is extremely probable that the formation of the graphite plus the cementite taken jointly is restricted by sudden cooling.[23] It is further probable that a very rapid cooling may completely prevent the multiplication of phases here. Take, for instance, a low-carbon cast-iron with 2.25 per cent. of carbon, which on slow cooling should yield a mixture of 2 per cent. austenite plus enough graphite or cementite or both to represent the remaining 0.25 per cent. of carbon. It is probable that a sufficiently rapid cooling of such a cast-iron—for instance, by granulating it in a freezing mixture—would completely prevent the formation of either cementite or graphite in freezing, so that the cast-iron when it reached the eutectoid range would consist wholly of supersaturated austenite.

§ 56 B. *Local coalescing*, too, must evidently be lessened by rapid cooling, both directly and indirectly. That it is lessened is a matter of common observation. Coarse graphite in cast-iron and well-marked pearlite in steel are to be had only by slow cooling. An extremely rapid cooling prevents the formation of pearlite altogether, and gives us nothing but martensite or austenite or both. A slower cooling may give us sorbite, which we may conjecture to be nothing but extremely finely-divided pearlite; and usually, the slower the cooling the coarser is the pearlite—*i.e.*, the further has the coalescing of the particles of ferrite and cementite respectively progressed. (There are unexplained exceptions.)

Here rapid cooling probably acts both directly and indirectly; directly, by denying the time needed for the migration of the islets of ferrite and cementite which this coalescing implies; indirectly, by lessening the quantity of ferrite and cementite which form by the decomposition of the initial austenite. A cooling so rapid as to prevent altogether the formation of ferrite and cementite necessarily thereby prevents their coalescing. A cooling rapid enough to restrict the formation of ferrite and

[23] In exceptional cases it has been found that sudden cooling actually increased the proportion of graphite. These need further study. Compare Hogg, *Journal of the Iron and Steel Institute*, vol. xlvi. (1894, No. II.), p. 108.

cementite to a very small amount, thereby restricts the quantity of these two substances which can coalesce. In other words, substances which do not exist because their formation has been prevented, cannot coalesce.

I understand that the segregation of lead-bearing statuary-bronze is of this class. A small quantity of lead is added to the bronze by certain founders, to make it softer and easier to cut with the finishing-tools. I understand that in order to prevent the spotting of the surface of these castings by the local segregation of the lead, they are stripped from their molds as soon as they are firm enough not to sag, and are cooled with water.

My purpose in dwelling on these things is to show that they differ essentially from the axial segregation which we are studying.[24]

§ 56 C. *Axial segregation.* It seems very clear that the direct effect of rapid cooling must be to lessen axial segregation for reasons like those which we have just been considering; but there is an indirect effect of rapid cooling which opposes this direct effect—viz., its diverting the course of solidification from the land-locking towards the onion type, or, in short, preventing the segregated matter from being locally pent up around the edges of the narrowing molten lake, and thus leaving it free to migrate centerwards. Let us consider these things separately.

First, let us note that axial segregation probably occurs almost wholly during the true solidification of the mass—*i.e.*, during the passage from the molten to the solid state—and is not materially increased by the transformations which occur in the eutectoid range, or by local coalescing. By the time that the eutectoid range is reached, the metal is so rigid that migration must be extremely slow; and axial segregation necessarily implies migration. The impurities found in the axial segregate must have traveled considerable distances in order to reach it. Local coalescing, instead of adding to axial segregation, should if anything work against it, as the least reflection shows. When two neighboring islets, for instance of ferrite, coalesce, the center of the resultant island is likely to be, not on the axis-ward but on the outer side of the center of

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[24] See Appendix, p. 274.

gravity of the two constituent islets, because that one of these islets which is initially nearer the axis of the ingot is slightly freer to move than the other, because it lies in slightly warmer and hence less rigid waters.

Let us now consider the conditions during solidification. To fix our ideas, let us consider the segregation of the carbon, for what is true of it is in a general way true of the other segregating impurities, the phosphorus and sulphur.

Let us picture in our minds that the mechanism of freezing is that a given layer in freezing splits up into two sub-layers of equal mass (note the distinction between layer and sub-layer), an impoverished one which freezes and an enriched one which stays molten; and that this latter immediately associates itself with its neighboring molten sub-layer to form a new molten layer, which will be the next to freeze by splitting up and depositing its impoverished half in like manner against the last frozen sub-layer, and turning over its other and enriched half to unite in turn with the adjacent molten sub-layer, and so on.

Then, to fix our ideas, let us consider the case of a 2.25 per cent. carbon cast-iron, Q', Fig. 30, of which the very first sub-layer has just deposited, with composition m, so that, because this sub-layer and the molten one just liberated are of equal mass, this latter has been enriched just as much as the frozen one has been impoverished, or by $m - n$, so that its composition is $m + m - n = p$.

The present composition of the layer which next will freeze, being made up in equal parts of this just liberated sub-layer with p per cent. carbon and a new sub-layer from the mother-metal with its old composition, m, has the composition $m + p \div 2 = p'$. But this littoral layer at once begins to grow poorer and poorer in carbon, because, being thus initially richer in carbon than the rest of the molten metal, its excess of carbon at once begins diffusing axis-wards into that mother-metal. Further, the slower the cooling is, the further will this axis-wards diffusion and the consequent impoverishment of the littoral layer have gone at the instant when it in turn splits up and deposits a second frozen sub-layer. Next, the further this impoverishment of the littoral layer has gone when it thus splits up, the poorer in carbon will be the new frozen sub-layer to which it gives birth, because the carbon-content of each

sub-layer deposited is due to the carbon-content, not of the average of the whole molten mother-metal, but of the littoral layer from which this sub-layer is formed.

If, for instance, absolutely no time elapsed between the freezing of the first and that of the second sub-layer, then the composition of the layer from which the second sub-layer is born would be $p' = p''$, and the composition of the sub-layer freezing out of it would be m'; whereas, if diffusion had plenty of time to work, so that, by the time the second sub-layer froze the carbon-content of the layer from which it freezes had fallen back

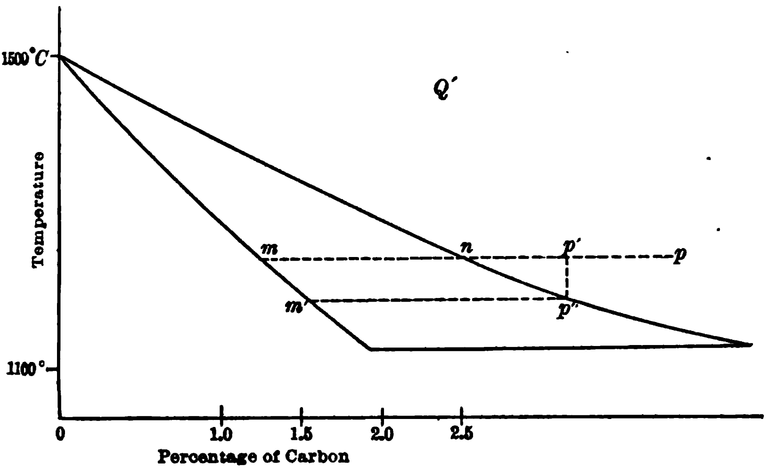


FIG. 30.—INFLUENCE OF THE RATE OF FREEZING ON THE COMPOSITION OF THE SOLID LAYERS DEPOSITED, AND THUS ON AXIAL ENRICHMENT.

very nearly to n, then the carbon-content of the sub-layer now freezing would be very nearly m.

Hence the more rapid the cooling the richer will be this second-freezing sub-layer, and the less will be the enrichment of the molten mass as a whole, and finally, the less will be that final axial enrichment which results from the enrichment of the successively frozen sub-layers.

To put this same thing in other words, each sub-layer as it freezes rejects a part of its carbon into the adjoining molten littoral layer. If this cooling is slow, so that some time elapses before this next layer itself freezes, then most of this rejected carbon will have worked its way centerwards by diffusion and

convection, and will thus have swelled the axial enrichment in carbon. But if cooling is very rapid, then, when this next layer freezes, there will have been so little time for diffusion and convection to do their work of transporting this rejected carbon that most of it will still remain in this next layer when it freezes, so that an undue proportion of the whole will be locked up by this freezing, instead of migrating centerwards.

Each step in this reasoning seems to follow irresistibly from the preceding, so that the whole chain seems to demonstrate that the direct effect of rapidity of cooling must needs be to lessen axial segregation. And however much we may dispute the accuracy of the picture here drawn of the mechanism of solidification, yet whatever be our conception of this mechanism, this same conclusion must, I believe, follow from it.

There is a second and closely related way in which rapid cooling may lessen axial segregation. With a given carbon-content of the layer in the act of freezing, there is a normal and proper degree to which the sub-layer which actually freezes transfers its carbon to the sub-layer which remains molten. It is probable that rapidity of freezing interferes with this transfer, lessens the amount of carbon which is thus tranferred from the sub-layer which freezes to that which remains molten, and thus locks up an abnormal quantity of carbon in the frozen layers, and thus lessens the carbon available for axial enrichment.

To sum this up, rapid cooling probably acts in a double way: first, by preventing diffusion and convection from sending axiswards from the layer about to freeze its excess of carbon, so that that layer is unduly rich in carbon when it starts to freeze; second, by restricting the transfer of carbon from that fraction of this layer which actually freezes to that which remains molten, so that the freezing sub-layer locks up more than its due share of the carbon present. In short, with sudden cooling, the carbon in each layer as it starts to freeze is unduly great, and of this unduly large quantity an undue proportion is locked up in the sub-layer which freezes. Thus the axial enrichment is robbed in two ways.

§ 56 D. *How sudden cooling may increase axial segregation.* This it may do both by restricting diffusion in the frozen

metal, and by diverting the solidification from the "land-locking" towards the "onion" type of freezing.

Though, as we have seen, diffusion and convection during freezing itself tend to increase the axial segregation by carrying the carbon ejected by the freezing metal away from the freezing region and towards the axis, yet after the metal has solidified, diffusion tends to lessen segregation, both axial and local, by re-distributing evenly the elements which segregation has localized. Hence, while slow cooling, by giving opportunity for diffusion, favors segregation during freezing, yet after freezing it tends to undo the segregation which has taken place.

That there should be less segregation when freezing is of the onion type than when it is of the land-locking type was explained at the beginning of § 54, p. 243. That slow cooling should favor the land-locking type, with its large, far-outshooting crystals, and that sudden cooling should oppose it, is both natural and in accordance with common observation. The steeper thermal gradient of sudden cooling leads to stronger convection-currents and a sharper evolution of gas, both of which tend to wash off the incipient pine-tree crystals. Again, the stronger convection-currents, by constantly changing the condition of the bath in which a given pine-tree crystal is growing, weaken the tendency of crystallization to adhere to its established axes, somewhat as continuous transplanting would kill a real pine-tree. Still again, the rapid forward motion of the shore-line in sudden cooling lessens the advantage which the established crystalline axes have of conducting heat outwards rapidly along well-established lines of thermal transit, in compact metal, and thereby lessens the attraction which their temperature thus lowered offers to the localizing of freezing—*i.e.*, to making it follow them, trunk and branch.

To sum up, we should expect rapid freezing to oppose axial segregation both by lessening the axis-wards diffusion (in the molten mother-metal) of the impurities rejected by the freezing layers, and by lessening the transfer of those impurities from each sub-layer as it freezes to its fellow sub-layer which remains molten. But we should expect it to increase axial segregation both by shortening the time which diffusion in the solid metal has for undoing the segregation which has occurred in freezing, and by preventing the land-locking of the impurities along

the shores of the freezing lake, and thus leaving them free to migrate axis-wards.

Under these conditions we should expect that the balance of these opposing conditions would vary both in quantity and in sign from case to case; so that sudden cooling should sometimes increase and sometimes lessen axial segregation, and its effect should often be slight. There may be a certain intermediate rate which gives the least segregation.

§ 57. *The evidence briefly considered.* Turning now from deduction to induction, we find the contradictory evidence which we have thus been led to expect.

In the majority of cases which have come to my notice rapid cooling increases axial segregation, an effect exactly opposite that generally attributed to it. Thus Roberts-Austen[25] (then Mr. W. C. Roberts) found nine times as great axial segregation in a rapidly-cooled alloy of 92.5 per cent. of silver and 7.5 per cent. of copper as in a like ingot cooled slowly. In three out of four cases I found slightly more segregation of sulphur in cast-iron ingots cast in iron molds than in like ingots cast simultaneously in sand molds from the same ladle through a double funnel or distributer. These ingots were cast for me by Mr. T. D. West, Sharpsville, Pa., to whom my most sincere thanks are hereby given. Jars,[26] in 1781, asserted that preheating the molds lessened the axial segregation of certain copper-silver alloys, and E. Seyd proposed in 1871 the use of hot molds for casting gold and silver, because this made the bars "more equal in temper and in molecular arrangement."[27] This pre-heating would certainly lead to the slower freezing of the alloy.

Turning from these cases in which rapid coöling increases axial segregation, we have some in which it has the opposite effect. Thus I found a little more segregation in an extremely slowly frozen alloy of about 96 per cent. of copper and 4 per cent. of silver, than in this same alloy when cooled extremely rapidly.

[25] On the Liquation, Fusibility, and Density of Certain Alloys of Silver and Copper, by W. Chandler Roberts, *Proc. Royal Soc.*, vol. xxiii., pp. 481 to 495 (1875).

[26] "Je remarquai par des expériences que pour rendre les lingots d'une teneur plus égale dans toutes les parties il falloit que les lingotières fussent aussi chaudes qu'il est possible." Quoted by W. Chandler Roberts (*op. cit.*, p. 492) from Jars, *Voyages Métallurgiques*, iii., p. 270, 1781.

[27] Quoted by W. Chandler Roberts, *loc. cit.*

The spot richest in silver had 4.88 per cent. of that metal in the slowly-cooled alloy, but only 4.57 per cent. in the other. These ingots were made under my direction by Dr. E. F. Kern and Mr. R. C. Blanchard, and the analyses were made by Dr. C. Offerhaus, whom I thank most warmly for their care and skill. The difference in degree of segregation is slight compared with the extreme difference in the rate of cooling. It is just such a moderate balance as might easily result from the struggle of opposing forces such as we have pictured.

Again, the relatively rapid freezing of the outer crust of a steel ingot seems to lessen segregation. Thus, in Mr. Stevenson's ingot, Fig. 13, if segregation had not thus been obstructed locally, there would have been an uninterrupted increase in carbon from the very outer crust to the central richest point in the segregate; but, instead, the carbon is higher, 0.60 and 0.61 per cent., in the lower corners than in any part of the interior except the immediate neighborhood of the pipe. This condition of affairs is not the exception but the rule, if we may judge from the considerable number of cases at hand.

This fact that there is a greater percentage of carbon and the other segregating elements, phosphorus and sulphur, in the very first freezing parts than in those which freeze slightly later, that as we pass inwards these elements first decrease suddenly, and then again increase slowly, seems clearly to mean that the sudden freezing of the outer crust has locally obstructed segregation, whereas the much slower freezing of the deeper-seated parts has given segregation much freer play.

Finally, the evidence which I have as to the influence of the rate of cooling on the segregation in the freezing of aqueous solutions is self-contradictory. One eminent maker of very pure chemicals informs me that the purest crystals are to be had by rapid crystallization,[28] another of equal eminence asserts exactly the opposite.[29]

I infer that the effect of the rate of freezing cannot be marked and constant, because if it were it should have forced

[28] "A purer product can be obtained by rapid crystallization." "Rapid cooling with stirring to prevent the formation of large crystals always gives a more satisfactory product."

[29] "The rate at which crystals are made to deposit both from aqueous and from solutions of organic solvents, has a very material effect on the purity of the resultant crystals. The faster the crystallization, the more impure the crystals."

itself on the attention of these competent observers, and it certainly should not allow them to form exactly opposite opinions.

The freezing of a metallic ingot and the deposition of crystals from an aqueous mother-liquor are of course strictly parallel, and the fact that in the latter case the mother-liquor is not frozen through and through does not affect the parallelism. Greater purity of crystals means a more thorough rejection of their impurities into the mother-liquor, and this in turn means a greater concentration of those impurities in the axial liquid when the freezing or crystallization nears completion.

The observation of one of these gentlemen that stirring increases the purity of crystals agrees with the reasoning in § 56 C. Stirring carries away from the surface on which freezing is taking place the sub-layer which, by the freezing-out of its mate, has just been enriched in the impurities present, and sweeps those impurities away into the general mass of the mother-liquor instead of leaving them in place to befoul the next deposited sub-layer.

In a later paper I hope to present the results of further investigations now in hand.

§ 58. *Means of varying the rate of solidification.* Of the means enumerated in § 53, the casting-temperature and the temperature and thermal conductivity of the molds need no explanation. It is evident that, if the steel is far above its freezing-point when cast, when it shall have cooled down to that freezing-point it will already have given up much heat to the walls of the mold, and thus in effect will have pre-heated that mold, which, because pre-heated, will abstract heat the more slowly from the freezing steel, and therefore the steel will from this time on cool more slowly than if it had been close to its freezing-point when cast, and thus had not so far pre-heated its mold when it reached the freezing-point.

But the effect of slow casting deserves a word of explanation, because here the conditions are not so simple. If casting is extremely slow, then, when the upper part of the ingot is pouring, the lower part will already have cooled far below its freezing-point, and hence heat will flow rapidly from the upper part into the now much cooler lower part. Hence the cooling and freezing of this upper part will be quicker than if the lower part had not thus been cooled off. Carrying this idea far

enough, any given stratum of steel on reaching the steel previously in the mold will find itself underlaid by a thin stratum of steel, itself solidifying rapidly because of the coolness of the metal below, and hence quickly cooling the stratum now arriving to and past its freezing-range.

To go one step further, if each layer of steel solidifies before the next layer reaches it, then the matter axially segregated in a given layer cannot coalesce with that in the layer above, so that the vertical migration of the segregated matter would be completely stopped.

In pouring wax ingots extremely slowly into a mold surrounded by ice-water, Prof. Stoughton and I found that, instead of the single large axial segregate which we got at the same time by pouring half of this wax extremely rapidly into a like ingot, this slowly-poured ingot had a series of minute axial segregates, each nearly horizontal, as if one layer at a time had segregated independently of the metal above and below. This we referred to the freezing across of the surface at different depths when our pouring became unusually slow, or was even discontinued for a very brief time.

It is extremely probable that the degree of enrichment of these small axial segregates is much less than that of a single axial segregate, because this latter is enriched not only by the horizontal migration of matter at its own level, but besides this by the vertical migration of matter from above and from below towards the last-freezing spot. If the segregate is to be got rid of by boring out the axial part of the ingot, this slow-pouring procedure has much to recommend it. But if the segregate is to be removed by cropping off the top of the ingot, then this slow pouring may have the disadvantage of, in effect, lengthening out the segregate or at least lengthening out the region in which serious segregation exists, perhaps increasing the quantity of metal which has to be rejected on account of the segregate, and possibly even making it impracticable to get rid of the segregate by end-cropping.

§ 59. *May segregation be desirable in certain cases?* Segregation is itself a purifying process, concentrating the impurities into the last-freezing part. If enough of this can be cut away and rejected, an important degree of purification may be had. We have already considered removing the segregated part by

cropping, but in many cases it is removed by boring out the central part; for instance, in preparing ingots for hollow forging, and in boring out the chambers of hollow projectiles. In still other cases the axial part, into which the impurities are concentrated by segregation, is relatively unimportant; for instance, because it is close to the neutral axis of a piece which has chiefly to resist transverse stress, or of a shaft which has chiefly to transmit rotary motion, or of an armor plate of which the face and back are the important parts.

In many such cases it may at first appear that segregation ought to be stimulated, so that its purifying effect may be increased. If segregation could be limited to the harmful elements, phosphorus and sulphur, this might indeed be a very attractive plan. Unfortunately, along with this purification goes, and must go, a corresponding irregularity in carbon-content.

This latter irregularity itself, and the harm which it does, naturally increase with the carbon-content of the piece as a whole; and hence, though in case of low-carbon steel it may be unimportant, and therefore to be tolerated because of the accompanying concentration of phosphorus and sulphur into a harmless position, yet in high-carbon steel its harm is likely to outweigh any such incidental advantage.

Indeed, each case must be judged on its own merits, weighing the harm which the irregular distribution of carbon may do against the good which may come from the concentration of phosphorus and sulphur.

In case of basic open-hearth steel, purity can in general be bought more cheaply by eliminating phosphorus and sulphur than by segregating them into a harmless position, and this should be especially true if the electric purifying processes keep their promise.

And though, in case of acid open-hearth steel, it may often be well to weigh carefully the penalty of irregular carbon-content, which we have to pay if we get our purity through segregation, against the high price of extremely pure raw materials which we should otherwise need; yet this latter price will probably be found less than that penalty in the great majority of cases, and, indeed, in a majority which will increase as time goes on.

§ 60. *Fluid compression may raise the segregate* towards the top of the ingot, and so lessen the proportion of the upper part which must be rejected in order to get rid of the segregate. In ingot *D* of Fig. 1, p. 172, the richest of the segregation should lie about *K*, somewhat above the center of the molten lake, because the segregated matter is lighter than the rest, as pointed out in § 45A (p. 233). If, when matters have reached this stage, the ingot is compressed, the still-molten metal may be forced up so as to fill the empty space which now constitutes the pipe. In effect, we make use of the empty space, the pipe itself, as a receptacle into which we may squeeze the molten segregate, now lying below it.

The effectiveness with which we may thus raise the segregate into the pipe, into this space left vacant by the ebb of the tide, depends both on the time and on the manner of applying the compression. This should be applied late during the solidification, so that there may be a large cavity into which the segregate, now reduced to a small bulk, may be effectively lifted; and it should be applied lower down than the bottom of the pipe, so as to leave the pipe of its full size, and therefore with the maximum capacity for receiving the segregate. So far as I know, these considerations, which I will now elaborate, are here set forth for the first time.

§ 61. *Time of applying the compression.* If the compression is applied in stage *B* of Fig. 1, when the quantity of molten steel is still great, the quantity lifted would be great, and the distance through which it would be lifted would be small. If, on the other hand, compression is deferred until stage *D*, the volume of the pipe is greater and the quantity of metal to be lifted much smaller; so that in this case the vertical travel, or the distance which the segregate is lifted, is much greater. If the large end of the ingot is uppermost, and if the cooling of the top is retarded by the several devices of top-pouring, slow-pouring, and using a pre-heated sinking-head, and by the natural action of the segregation itself (§ 45), so that the state of affairs is more like that sketched in Fig. 32, then compression should have a very important effect in lifting the segregate.

Clearly, the later in the freezing the compression is applied, the farther will it lift the segregate towards the ingot-top, but the smaller will be the quantity of this segregate thus lifted,

and the richer in impurities will be those axial parts of the ingot left after the segregate has thus been lifted. The reason for this last fact is that, other things being equal, the richer the mother-metal is in any given impurity, the richer in that impurity will be the steel which freezes out, layer by layer, from that mother-metal; so that as freezing and segregation proceed, and the mother-metal grows progressively richer in the impurities, so is each layer of solid steel which freezes out of that mother-metal richer in those impurities than the last preceding layer; and this goes on until the layers which are depositing may become prohibitorily impure.

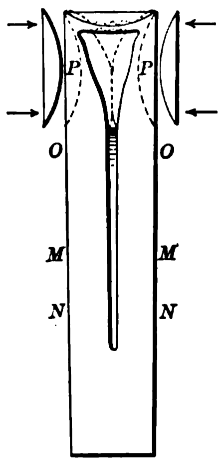


FIG. 31.—HIGH-LEVEL LIQUID COMPRESSION PREVENTS RAISING THE SEGREGATE.

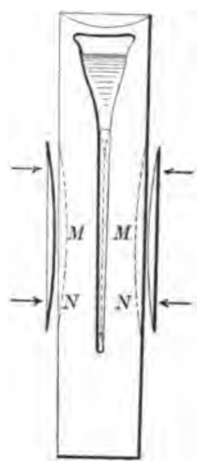


FIG. 32.—LOW-LEVEL LIQUID COMPRESSION RAISES THE SEGREGATE INTO THE PIPE.

The dotted lines show the state of things after applying the compression.

In view of this, the time at which we should aim to apply the compression should be that at which the percentage of impurities—for instance, of phosphorus—in the layers now freezing, has risen as near as is safe to the permissible limit for phosphorus. Compression applied then should leave in the unlifted frozen part no layers prohibitorily rich in impurities; and it should lift the segregate as far towards the top of the ingot, and thereby diminish the percentage of cropping needed to remove that segregate, as far as is compatible with having no part of the remaining ingot prohibitorily rich in any impurity.

This time could never be hit with exact accuracy; but careful experiment thus directed might enable us to time the com-

pression advantageously. And, of course, the compression should not be so long delayed that the ingot's crust has become too thick and rigid to be compressed effectively by the means at hand.

§ 62. *The manner of applying the compression.* In order to lift the segregate most effectively, we should avoid narrowing the pipe itself, and we should chiefly narrow the molten lake, as, for instance, by applying pressure at points below its surface, as at *MM* and *NN*, Fig. 32. Thus, if we should first apply pressure at *PP*, Fig. 31, by pressing together a pair of convex pieces there, we should close up the cavity; and if, while holding it thus closed, we should next apply pressure at *OO*, *MM* and *NN*, this pressure could not lift the segregate, because there would no longer be an empty space into which to lift it. If, on the other hand, pressure is applied through like convex pieces at *MM*, Fig. 32, and none is applied at *PP*, then the compression should lift the segregate very effectively, because the volume of the empty space which is to receive it has not been lessened by the compression.

There are four prominent methods of applying the pressure: lengthwise (Whitworth's); sidewise uniformly (Illingworth's); endwise in a conical mold, which results in uniform sidewise compression (Harmet's); and sidewise, chiefly near the middle of the ingot's length (Williams's).

To refresh the reader's memory, I will first describe these processes briefly, and then consider how they compare as means of lifting the segregate, and thus lessening the cropping needed.

§ 63. *In Whitworth's system*[30] the ingot is cast in a vertical cylindrical iron mold, *L*, Fig. 33, strongly hooped, *K*, and lined with molding-sand, *N;* and it is compressed lengthwise by being pressed up against the fixed ram, *G*, during and after solidification.

§ 64. *In Illingworth's system,*[31] shown in plan in Fig. 34 at two stages, the ingot is cast in a vertical mold of the usual shape, but split lengthwise. During the casting of the ingot, the two halves of the mold are held a little apart, as shown at

[30] *The Metallurgy of Steel*, H. M. Howe, p. 155.

[31] Piping in Steel Ingots, by N. Lilienberg, *Bi-Monthly Bulletin*, No. 9, May, 1906, pp. 327 to 336.

I., and the crevice thus formed between them is temporarily stopped with specially shaped distance-bars. As soon as the crust of the ingot has solidified to a proper thickness, these distance-bars are pulled lengthwise out from between the two halves of the mold, and these halves are then forced together

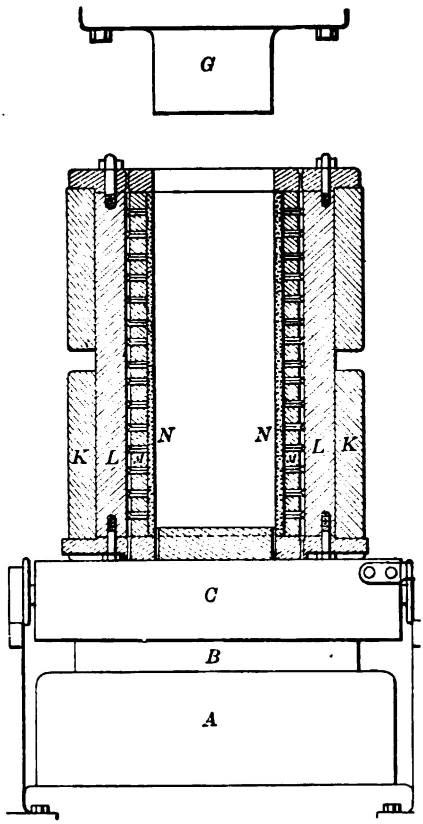


FIG. 33.—WHITWORTH'S HYDRAULIC PRESS FOR THE COMPRESSION OF STEEL INGOTS WHILE SOLIDIFYING.

A, main compression-cylinder. *B*, its plunger. *C*, the carriage on which the mold or flask sits. *G*, boss against which the steel in the mold is forced. *KK*, steel jackets for the mold. *LL*, the mold proper. *MM*, perforated cast-iron lagging. *NN*, inner sand lining.

by the ram, *F*, to the position shown at II., of course compressing the ingot horizontally by the amount by which the two halves originally gaped apart in I.

We should expect that the compression would force the steel out into the groove between the two halves of the mold, left

vacant by the removal of the distance-bars; but we are told that it does not. If trouble from this source should arise, the distance-bars could be shaped as I have shown them, so as to make an initial groove on the side of the ingot, which the compression and the subsequent rolling would efface.

§ 65. *In the Harmet or "draft-compression" system,*[32] Fig. 35, the ingot, *AA*, is cast as the frustum of a slightly tapering cone, in a conical mold, and is then forced up towards the apex of the cone by means of pressure applied at its base. As when a tapered plug is driven into a tapered hole, the pressure exerted against the sides of the hole is enormous; so here,

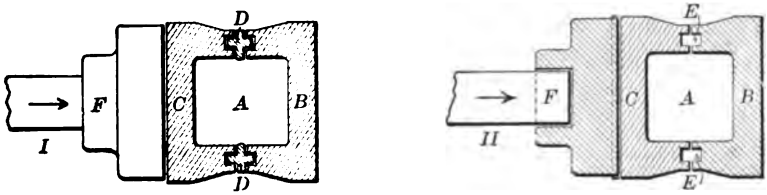


FIG. 34.—ILLINGWORTH'S PRESS FOR COMPRESSING STEEL INGOTS HORIZONTALLY WHILE SOLIDIFYING. Sectional Plans.

In I. the mold is shown ready for receiving the molten steel. Two distance-bars, *DD*, are set between the halves of the split mold, *B* and *C*. After the steel has been poured into the mold, these distance-bars are pulled out lengthwise, and the two halves of the mold are then forced towards each other by means of the ram, *F*, as shown in II. The convex edges of the distance-bars are for the purpose of making an initial depression in the side of the ingot, lest part of its side should be forced out as a fin or welt into the crevice between the two halves of the mold. N. Lilienberg, *Bi-Monthly Bulletin*, No. 9, May, 1906, pp. 327 to 336.

because action and reaction are necessarily equal and opposite, there is, in effect, an enormous inward radial pressure upon the surface of the ingot. A moderate pressure at its base causes an enormous pressure on its sides. The progressive narrowing of the ingot as it travels up through the mold causes incipient but instantly effaced puckering, and forces the metal centripetally to fill up the pipe as fast as it forms.

§ 66. *In S. T. Williams's system*[33] the ingot is cast in a split mold, as shown at I. in Fig. 36. As soon as its walls have be-

[32] *Journal of the Iron and Steel Institute,* vol. lxii. (1902, No. II.), pp. 146 to 207. H. M. Howe, in the Report of the Commissioner General of the United States to the International Universal Exposition, Paris, 1900, vol. v. *Iron, Steel and Other Alloys,* H. M. Howe, p. 373. *Journal U. S. Artillery,* March–April, 1905.

[33] *Metallurgy of Steel,* H. M. Howe, p. 156; U. S. Patent 331,856, December 8, 1885.

come firm enough to stand unsupported, the two halves of the mold are drawn apart, as shown at II., a liner, B, is slipped between ingot and mold, and the mold itself is covered with a strong cap. The right-hand side of the mold is then pressed to the left by the ram, C, forcing the liner, B, against the ingot, and bringing matters to the condition shown at III. The forcing-in of the initial bump or convexity of the right-hand side of the ingot squeezes the molten steel up into the pipe.

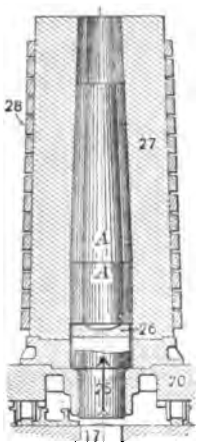


FIG. 35.—HARMET'S LIQUID COMPRESSION BY WIRE-DRAWING.
The ingot, AA, is cast in a strong conical mold, 27, reinforced with hoops, 28. Strong pressure at the base of the ingot, 26, forces it lengthwise of the mold, thus compressing it radially.

I should have expected some difficulty from the squeezing of the steel into the crevice between the two halves of the mold. But, when I saw the process in actual use, this trouble did not appear to arise, probably because, by the time the compression was applied, the bottom of the ingot had grown cool and firm enough not to squeeze into the crevice.

§ 67. *Relative effect of these four systems in raising the segregate.* Let us now consider the relative merits of these four systems, regarded as means of lifting the segregate, and thus lessening the quantity of metal which must be cropped from the top of the ingot in order to get rid of this segregate.

§ 68. *Whitworth's system.* As the outer walls of the ingot solidify and begin to contract, they tend to draw inwards and away from the walls of the mold, leaving an annular space between; but the lengthwise pressure, shortening those walls, and thereby thickening them, both squeezes them out so as to keep them in actual contact with the walls of the mold, and thickens them inwards as fast as the pipe-forming tendency gives any room for this inward forcing. If a pipe were allowed to form before the pressure was applied, then this inward forcing of the walls would in effect lift the molten interior into that pipe. And if the pressure is applied continuously throughout the period when the pipe tends to form, it in effect lifts this molten interior to fill up this nascent pipe as fast as it tends to

form, so that at first it seems to offer a good means of raising the segregate, and thus of lessening the amount which has to be cropped off in order to get rid of the segregate. But there are three things which seriously interfere with the effectiveness of this raising of the segregate, as I will now explain.

The first is, that the compression tends to close up the pipe by squeezing its walls in earlier than it squeezes together the walls of the lower part of the ingot, because the first applied pressure will, of course, take its greatest effect where the walls of the ingot are the softest and thinnest, and this will be near the top where the pipe is beginning to form. The reason for this is, that the solidification at the bottom of the ingot outruns

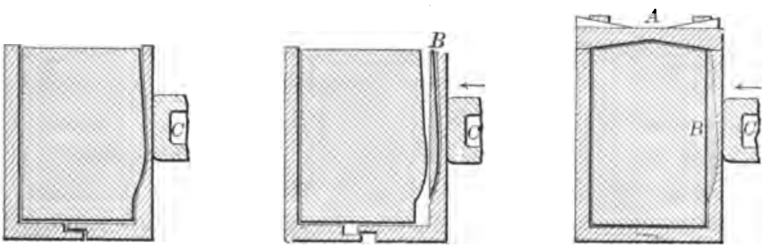


FIG. 36.—S. T. WILLIAMS'S ABDOMINAL LIQUID COMPRESSION FOR SOLIDIFYING STEEL INGOTS.

The ingot is cast in its mold, as shown at I. After its outer crust has solidified, the mold is opened, as shown at II, and a liner, *B*, is slipped between mold and ingot. A strong cap, *A*, is then fastened down, and by means of pressure applied through the ram, *C*, the abdominal protuberance on the ingot is forced in, so as to close the pipe and lift the segregate into it, as shown at III.

that at the top; first, because the bottom is cast first and is cooling off while the top is receiving fresh additions of hot steel from the casting-ladle; and, second, because of the cooling-effect of the bottom of the mold. In short, because at any given moment the upper part of the walls is thinner and softer than the lower part, the compression tends to close up the pipe faster than it squeezes up the metal from below to enter it; and this is our first reason why Whitworth's system is at a disadvantage as regards lifting the segregate.

The second reason is the fact that, in order to compress the ingot lengthwise, Whitworth's system has to compress lengthwise the firmest part of the ingot, to shorten the hollow column of solid steel which at any moment during the freezing

has already solidified against the walls of the mold, and to shorten it by a direct pressure applied at its end, where it offers the greatest resistance to compression. In Harmet's system the pressure has the very great advantage of the wedge shape of the mold; in Illingworth's system the ingot naturally bulges in or crumples at its sides, along the plane where the distance-bars have been, where its walls are much thinner than they are at the corners. In Williams's system the flat side of the ingot at its thinnest part is forced in laterally. Compared with Whitworth's system, this is like attacking a column by horizontal pressure applied at the middle of its length, its part of least resistance, instead of by vertical pressure at its end, its part of greatest resistance.

Now, this very fact that Whitworth's compression attacks the ingot along its line of greatest resistance leads to the need of beginning the compression very early, before the column has become too strong to be compressed. But, as we have seen in § 61, this early compression, before the pipe has reached any considerable size, implies raising the segregate through only a very small distance.

The third reason is that Whitworth's endwise compression, in bulging out the sides of the ingot as fast as they tend to draw away from the walls of the mold, is like pressure at the end of an ill-hooped barrel, which makes its staves yawn open. Whitworth's compression, in like manner, is very liable to crack the thin and mushy walls of the ingot, which have neither the mobility of the liquid state nor the ductility of the solid state, to make them yawn open like the staves of a barrel, to squeeze the segregate out into them instead of raising it up into the pipe, and thus to give a series of hard longitudinal strips of segregated matter at the skin of the ingot.

This defect of Whitworth's system, that it does not lift the segregate efficiently, is quite apart from its defect of attacking the ingot along its line of greatest resistance, and thus of needing the maximum of power.

§ 69. *In Illingworth's process*, the amount by which the walls are forced together by the compression should be the same in the upper part of the ingot as in its lower part.

§ 70. *In Harmet's process*, although it is true that the pressure is applied at the base of a conical ingot, yet this results in

a very powerful lateral compression, quite as when we drive a tapered plug into a tapered hole; and this lateral compression tends to raise the molten segregate up into the pipe, quite as in Illingworth's method. In one process as in the other, the amount by which the walls of the ingot are forced together should be the same in the upper part of the ingot as in the lower part.

§ 71. *In Williams's process*, Fig. 36, most of the lateral compression is in the middle and lower part of the length of the ingot, and the sides of the pipe are forced towards each other only relatively little; so that the chief effect of the compression, from our present standpoint, is to raise the segregate, and the amount by which it narrows the pipe and thereby impedes the raising of the segregate is very small. I do not know whether the inventor understood that his process might have this effect of raising the segregate. His object was to close up the pipe and blow-holes; but if the top itself is to be cut off and rejected after the segregate has thus been lifted into it, then it ought to be left uncompressed, so that the cavity in it which is to receive the segregate forced up from below should be left as large as practicable. In short, the compression should be restricted to the main body of the ingot, and the part which is to be cut off and rejected should not be compressed.

§ 72. *Summary.*—To sum this up, the beneficial lifting effect on the segregate should be the greatest in Williams's system, which compresses the ingot chiefly in the middle of its length; it should be the least in Whitworth's system, which compresses the ingot more at its top than elsewhere; and it should be intermediate in the systems of Illingworth and Harmet, which compress the ingot equally in all parts of its length.

III. Engineering Specifications.

§ 73. *Precautions in engineering specifications as to piping and segregation.* What steps should the buyer's engineer take to assure himself that the steel which he receives is free from injurious piping and segregation? Should he content himself with inspecting the finished products sent him, and not attempt to interfere with the manufacture, looking to the manufacturer for results, without question as to the means by which they are reached? Or, going to the other extreme, should he insist not

only on specifying all the conditions of manufacture, but also on inspecting them all, so as to assure himself that his specifications are actually obeyed? As usual, it is the part of wisdom to go to neither extreme, but, relying rather on skill than on brute force, to plan the specifications and inspection so that the evidence which they give as to the fitness of the steel may be as conclusive as is compatible with due regard to the maker's interests; that it may be easy to get and yet convincing.

It is unwise to be content with inspecting the finished product. This, indeed, might do well enough if each heat of steel were uniform throughout; but piping and segregation, two of the worst defects, are local, and not even thorough inspection of the finished steel can tell where they are at their worst. Even if inspection of fifty places taken at random, and therefore in the dark, should show no harmful segregation, yet at a fifty-first the segregation might be intolerable; and this intolerable segregation might thus escape the most searching of inspectors if he were thus blindfolded.

It is unwise to go to the opposite extreme and insist on specifying and inspecting all the details of the manufacture, chiefly because this would probably have the effect of preventing the most skillful makers from bidding, and thus not only limit competition and facilitate collusive bidding, but also cut off your best sources of supply. It would prevent many skillful makers from bidding, because it would threaten to reveal secrets, the exclusive possession of which may be of the greatest value to the manufacturer.

§ 74. *Secrecy.* At first, those whose training is chiefly in civil or mechanical engineering may ridicule this, and talk about keeping information in at the cost of keeping information out, and of the short-sighted policy of secrecy and concealment in general. But there is a real difficulty here, which often forces the metallurgist into a secrecy not only inconvenient and galling, but expensive and dangerous, dangerous because secret processes, unprotected by patents, are a temptation to larceny and blackmail difficult to prevent, resist, or punish.

§ 75. *Uncertainty of patent-protection.* The fact that, in spite of this danger, men otherwise sagacious and conservative will pay very large sums for secret processes, is good evidence that this difficulty of which I speak is real and serious. It lies in

the uncertain and insufficient protection which patents afford to many metallurgical processes, as distinguished from products. It is difficult to frame the patent specification, and extremely difficult to detect and prove infringements. Much of the value of the secret knowledge may lie in skillful execution of details, in the combination of steps each of which may be unpatentable because already known, just as no part of a sewing-machine may be patentable, yet the machine itself may be clearly patentable.

§ 76. *Difficulty of proving invention.* In case of such a mechanism we often can have some confidence that the courts will uphold a patent, because here the existence of real invention can readily be made clear. This is because all men are necessarily mechanics, dealing with statics and dynamics from the moment when their hands first grasp their infantile feet. Every motion which I take or which I see any man, animal, or other object take, instructs me in the essentials of mechanics. With chemical matters it is very different. They are more occult; they are not the object of daily thought and experiment. Still more so are metallurgical matters, based on the fearfully complex conditions and principles of physical chemistry, further complicated by the great ranges of temperature covered, each with its potent influence.

You hesitate to patent your metallurgical invention. To patent it reveals it to all your competitors with perfect certainty; "The gods themselves cannot recall their gifts;" but whether the courts will uphold your patent is extremely doubtful. Can you persuade the court that you have really exercised the inventive faculty? If, with all your skill, you fail to explain your metallurgical conceptions so as to force the unwilling controversial specialist to concede the truth of metallurgical views which to you seem absolutely unquestionable, how can you have any confidence that you can make a court, which has never thought of such questions, even understand you; and, granted such understanding, how can you hope to prevent it from becoming hopelessly confused by a skillful opponent?

§ 77. *Difficulty of detecting infringements.* Unpromising as the patentee's prospects thus are as regards proving that his invention really is an invention, they are equally unpromising as regards detecting infringements. If a machine or a mechanical

appliance is patented, each infringement is open to detection. Each piece which infringes the patent is its own evidence of infringement as soon as it reaches the market, and it remains valid evidence as long as it exists.

But a metallurgical process is generally only a means towards a desired specific result, and to prove that this means has actually been used is likely to be very difficult; first, because we can rarely either know or prove that its specific result has been attained; and, second, because, even if we knew that it had, we could rarely know or prove that it had been attained by our means. If, for example, the process aims to give certain particular excellent qualities to the steel, you can rarely know that any particular lot of steel, or even that the regular output of a given maker, really has those particular excellent qualities; and if you did know it, it would be difficult to assure yourself that it was by the use of your particular process that these qualities had been given. If my secret dog-mixture is the best, the fact that other dogs have won the blue ribbon is poor proof that they have fed on my mixture. Not every thin man eats my "anti-fat."

To prove suspected infringement often requires litigation, which is very uncertain in its outcome, but certain to be very costly and likely to reveal any secrets which the patentee of the particular process in dispute may not have patented. Thus the protection of patented processes by litigation may easily mean the revealing of any unpatented ones; so that, unless the manufacturer is willing to open everything, he may reasonably be loath to open anything to the prying of the patent-attorney and expert.

In many cases infringement can be proved only by putting the suspect's workmen on the witness-stand, not an attractive procedure to those who would live in good-will with their neighbors, and one which, by provoking retaliation, may lead to exposing any secrets which you yourself may have.

In many cases the product can in the very nature of things give absolutely no token of having been made by a certain process. For instance, how can one know from examining a piece of steel in what particular way it has been recarburized, what the procedure in the open-hearth furnace has been, or how the temperature of the Bessemer converter in which it has been made has been governed?

Even in case of clearly unpatentable inventions, reinventions of processes already disclosed, and therefore unpatentable, or processes covered by patents which have now expired, the manufacturer's exclusive knowledge may be of great and legitimate value. Of such a process he may find a valuable but apparently unpatentable application. He is under no obligation to inform his competitors that his quicker intelligence has discovered a useful way of applying this process, which to others has seemed useless.

For these and like reasons, to protect processes by patents is much harder than to protect products; and it is rarely wise to insist that all the steps of metallurgical manufacture shall be open to the inspection of the buyer's engineer, for this may result in excluding the most desirable bidders, and perhaps the only really competent ones.

We therefore ask, which steps of manufacture are most important to inspect, and which of these can and ought the manufacturer permit you to inspect? Of which is it to the buyer's interest to ask inspection, and of which can the manufacturer reasonably be expected to permit inspection?

§ 78. *Inspection at the rolls and shears, with axial drilling for the segregate*, seem the steps which are both the most searching and convenient for the buyer and the least objectionable to the maker.[34] A glance at the ingot before it enters the rolls shows its size, whether it has been top- or bottom-cast, and whether it has been cast with the large end up or down. The inspector further sees the finishing-temperature; he watches the cropping to see whether this goes properly beyond all unsoundness; and, probably most important of all, though hitherto overlooked, he can mark those blooms or billets which come from the upper end of each ingot, and mark their upper ends distinctively, so that he can later identify them, and by analyzing drillings from the axis of these pieces, learn whether all harmfully segregated parts have been cut off and rejected.

It is in the axis of the billet or bloom that the freezing must end, and therefore that the richest of the segregate must lie; and not only in the axis but in the axis near the upper end of the ingot, or at least near the upper end of the pipeless part of the ingot. If the conditions of casting and cooling are such

[34] Inspection of the finished product is of course assumed.

that serious segregation occurs, and if the cropping is carried far enough to remove all piped parts, then the richest of the remaining segregate will lie in the axis near the upper end of the remainder of the ingots. And if the drillings are taken from the axis of each end of the bloom coming from the upper end of the remainder of the ingot, or from the axis of each end of the two blooms or billets nearest the upper end, then if any harmful segregation has been left uncropped and unrejected, its presence is almost certain to be detected in the blooms from at least one and probably in those from several of the ingots of a given heat.

The inspector who proceeds thus is unblindfolded. Light is given him as to the position of the segregate, so that his investigation of its extent and harmfulness is made intelligently and with knowledge. He probably will not, indeed, find the very richest of the segregate, for this richest spot is at a mathematical point which is far more likely to lie between the two ends of the billet or bloom which contains it than at the very end, where it could be found by drilling. But the concentration or segregation is grouped onion-wise about its richest spot, and the enrichment from layer to layer is not abrupt but gradual. Rolling draws this onion out into a nest of long concentric pods. If any excessive segregation remains after cropping, these axial drillings, even though they do not reach the very richest of the segregate, are almost sure to detect very marked segregation in a billet or bloom from at least one ingot of a heat; and this detection in any one piece should lead to the rejection of the whole heat, or at least to closer scrutiny.

If the maker knows that inspection is thus to be made with light and knowledge, he will see that the chance of detection of any harmful segregation is so great that his interests should compel him to crop liberally.

To be specific, I suggest a clause somewhat as follows:

§ 79. "*Check-drillings.* In addition to the regular drillings taken from the ladle-test for analysis, check-drillings shall be taken from the parts suspected of being most strongly segregated; for instance, from the axis of each end of the two blooms, billets or slabs which come from the upper end of the ingot remaining after cropping. Drillings from each such place shall be analyzed separately, and all the steel of the heat from which said drillings have come shall be rejected in case

either the carbon or the phosphorus in said drillings exceed the limit prescribed for carbon and phosphorus respectively for the ladle-test, or in case the sulphur in said drillings exceeds the limit for sulphur set for the ladle-test.

Instead of absolute rejection, it may suffice in some cases to provide for further and more rigid search for segregation. For instance, the upper two blooms, etc., may be rejected, and axial check-drillings may then be taken from the next two blooms, etc.

The number of blooms, etc., of which axial drillings are thus to be taken should, moreover, depend upon the relation between the size of these blooms and that of the ingot from which they are cut. If the ingots are very large and the blooms unusually small, then more blooms should be inspected in order to make sure that the inspection has really reached below the richest of the segregate. Indeed, what I have here advised is *pro forma*, to be adjusted to the needs of each case.

§ 80. *Further precautions in engineering specifications as to piping and segregation.* Although the precautions just described, inspection at the rolls and taking axial drillings, seem to me both searching and reasonable, effective for the buyer and acceptable to the honest and competent maker, yet both for those who do not agree with me and for those who wish additional precautions, we may next ask what further steps are reasonable.

They may be divided into two classes:

I. Cropping, in order to remove the piped and segregated parts, and

II. Restraining piping and segregation, and raising the pipe and the segregate towards the top of the ingot.

§ 81. *Cropping.* Though, as regards segregation, the axial drilling discussed in sections 78 and 79 is a searching test, yet neither it nor cropping until the cropped section looks solid gives really good evidence that the harmfully-piped parts have been rejected. That axial drilling does not is self-evident; and that continuing to crop until the cropped section looks solid does not is clear on the least reflection. The walls of the lower part of the pipe are usually pretty smooth, so that in rolling they fold down and close together. If they are unoxidized, they will weld; but if, as usually happens, enough atmospheric oxygen filters in through the top of the ingot to oxidize these walls, then they are likely not to weld. Yet they

will be folded together so well that their unweldedness—*i.e.*, the fact that the pipe really constitutes a serious and persistent flaw—may not be apparent to the inspector, who is necessarily at some distance from the cropped section which he is inspecting, because it is so hot that he cannot hold his face near it.

Thus the apparent soundness of the hot cropped section gives no strong evidence that the cropping has gone deep enough to remove the harmfully-piped part, and of course it throws no trace of light on the question whether the cropping has gone deep enough to remove all harmfully-segregated parts, because the segregation usually lies far below the pipe.

Therefore, as a precaution against the presence of harmfully-piped parts, and as an additional precaution against that of harmfully-segregated parts, the buyer's engineer may reasonably specify, in important cases, that a certain predetermined percentage of the ingot's length shall be cut off, and that he shall inspect this off-cropping. This percentage should be based on the conditions of casting, and we should learn whether it is enough by examining certain individual ingots exhaustively, to see how deep in them harmful piping and segregation actually reach.[35]

§ 82. *Precautions in engineering specifications to restrain piping and segregation, and to raise the pipe and segregate towards the top of the ingot.* To recapitulate the steps already considered:

The pipe is shortened, though probably at the cost of increasing the degree of segregation:

(1) By casting in wide ingots;

(2) By casting in molds of low conducting power,—*i.e.*, lined with sand or clay—especially if pre-heated.

The pipe is shortened and the segregate raised:

(3) By top-casting instead of bottom-casting;

(4) By slow casting;

(5) By casting with the large end up instead of down;

(6) By retarding the cooling of the top by means of a sinking-head or otherwise;

[35] In several of the cases reported the very richest of the segregate lies nearly 30 per cent. below the top of the ingot; indeed, in one extreme case it lies nearly 60 per cent. below the top. Again, Dr. P. H. Dudley points out that "In many cases the A rail of the ingot—the top—will be sound and the next, or B rail, include a local portion of unsound metal which visual inspection fails to detect." (*Proceedings of the New York Railroad Club*, Nov. 16, 1906, p. 527.)

(7) By permitting deep-seated blow-holes to form through adjusting the quantity of silicon and manganese or their equivalent;

(8) By liquid compression.

The degree of segregation is lessened:

(9) By quieting the steel by adding aluminum or its equivalent;

(10) Probably by casting in small instead of in large ingots; and perhaps by steps which hasten the solidification, such as

(11) Casting at as low a temperature as practicable;

(12) Casting in thick-walled iron molds; and

(13) Casting slowly.

Of these, (2), (5), (6), (8), and (10) are not in such general use that it would be wise in most cases to call for them, because this would be likely to exclude many competent bidders, facilitate collusive bidding, and thus tend to raise the bids; and (1), (4), (7), (9), (11), and (13) can hardly be specified intelligently with the knowledge which the engineer has or can command at present; and even if they could, to specify them in effective detail would be to dictate to an unwelcome and unreasonable, indeed in certain cases to an intolerable degree, the details of the steelmaker's procedure.

But (3), top-casting, may reasonably be required in many cases, because it is not the exception but the rule, and because, in the very great majority of steel-works, to use it would involve no hardship, difficulty or considerable expense.

If we turn now from the common run of engineering specifications to those which not only are of unusual importance but also call for steel of unusual excellence, such as high-carbon steel for the wires of suspension bridges, we find three more of these precautions: casting (5) with the large end up, (6) with a sinking-head, and (10) in small ingots, not larger than 8 in. square, which may be considered very seriously. They are already familiar to most competent makers of such steel, and, indeed, are actually used by many of them. And, as the great value of these precautions in lessening the needed cropping and in raising the permissible limit of phosphorus and sulphur becomes better known, and as they thus become more

generally adopted, the proportion of cases in which they may reasonably be called for will increase.

Of the other precautions, *permitting deep-seated blow-holes to form*, (7), is already in very general use. Though the buyer may hardly go so far as to demand that there shall be blow-holes, their presence in small quantities is to his advantage, and therefore should not only be permitted, but even welcomed, both in castings and in ingots, in the former provided that they are so placed that they do not weaken the castings materially, in the latter provided that they are so deep-seated that their sides do not become oxidized, and therefore are not in danger of imperfect welding.

APPENDIX.

Segregation and liquation. The established meaning of liquation is the extraction of a more-fusible from a less-fusible metal, by heating them to a temperature between their respective melting-points, so that the former melts and runs out from the latter. But this word has been so often used by careful metallurgical writers to mean also the local coalescing, discussed in § 56 B, p. 246, as distinguished from axial segregation, that it seems well to recognize this meaning, which I hereby call to the attention of the Institute. Indeed, this local coalescing is a first step in the process of bodily extracting the more-fusible metal from the less-fusible one. Before the more-fusible metal can run out from the other, it must first coalesce locally into particles of considerable size. The trend of custom seems to be strongly in the direction of using "segregation" in the sense of axial segregation and "liquation" in this special sense of local coalescing. Thus used these two words facilitate the discussion of this most important subject.

The objection to this step is that "liquation" would then have two meanings, differing in degree. But the old and established meaning of "bodily extraction" is to-day of little use. There is to-day little need of a word to designate the "bodily removal" process, but there is great need of a brief and clear word to designate local coalescing.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

A Study in Refining and Overpoling Electrolytic Copper.

BY H. O. HOFMAN, R. HAYDEN AND H. B. HALLOWELL, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, BOSTON, MASS.

I. Introduction.

The object of refining copper in the reverberatory furnace is to obtain a metal which will have the highest attainable degree of malleability, ductility and electric conductivity, and present at the same time a level surface when it solidifies in the mold after casting. These desirable physical properties are governed by the character of the impurities and the forms in which they are present, by the amount of cuprous oxide retained by the copper, by the quantity of gas held in solid solution, by the casting-temperature, and by the thickness of the casting. The effects of impurities, of cuprous oxide and of gases upon the mechanical properties of copper have been studied by Hampe[1] in his classical paper "Contributions to the Metallurgy of Copper." The most recent research into the effect of metals upon the electrical conductivity of copper is that of Addicks.[2] The influence of cuprous oxide upon the electrical conductivity has been investigated by Walker[3] and Addicks.[4] The absorption of gases has received attention by Hampe,[5] Stahl[6] and Heyn.[7] The effects of casting-temperature have been noted by Stahl.[8]

[1] *Zeitschrift für Berg-, Hütten-und Salinen-Wesen in Preussen*, vol. xxi., pp. 218 to 283 (1873); vol. xxii., pp. 93 to 138 (1874).

[2] *Journal of the Franklin Institute*, vol. clx., p. 425 (1905); *Trans.*, xxxvi., 18 to 27 (1906).

[3] *The Mineral Industry*, vol. vii., p. 248 (1898).

[4] *Transactions of the American Institute of Electrical Engineers*, vol. xxii., pp. 695 to 702 (1903); *Electrochemical Industry*, vol. i., pp. 580 to 583 (1902-03).

[5] *Op. cit.*, vol. xxi., p. 274 (1873); also *Chemiker Zeitung*, vol. xvii., p. 1692 (1893).

[6] *Ueber Raffination, Analyse und Eigenschaften des Kupfers*, Fieke, Altenau i. Harz (1886); also, *Berg- und Hüttenmännische Zeitung*, vol. xlviii., pp. 323, 324 (1889); vol. xlix., p. 399 (1890); vol. lii., p. 19 (1893); vol. lx., pp. 77 to 79 (1901).

[7] *Zeitschrift des Vereines deutscher Ingenieure*, vol. xliv., p. 508 (1900); *Metallographist*, vol. vi., p. 48 (1903); also, *Metallurgie*, vol. iii., p. 82 (1906).

[8] *Op. cit.*

The present paper contains the results of two lines of investigations embodying (1) a study of the physical and chemical changes undergone by two charges of electrolytic copper at different plants while being refined in the reverberatory furnace, and (2) a study of overpoling electrolytic copper on eight tough-pitch and four furnace-overpoled samples from separate refineries. The physical changes considered were in appearance of surface, specific gravity, tensile strength, elongation and electric conductivity. The modifications in fracture and microstructure have already been studied by Hofman, Green and Yerxa,[9] and are therefore omitted. The chemical changes noted were confined to variations in the content of copper, iron, sulphur and oxygen, as the foreign substances contained in electrolytic copper are too small in amount to affect the present investigation. In the second part of the paper, the physical and chemical properties of samples of tough-pitch and of furnace-overpoled copper were studied; the tough-pitch samples were completely overpoled in crucibles and the ensuing properties of crucible-overpoled copper determined; lastly, crucible-overpoled copper was compared with native copper from Lake Superior.

II. Studies in Refining Electrolytic Copper.

1. *Refining-Charge No.* 1.

(*a*) *Samples.*—Twelve samples formed the basis of the first series of tests. They were taken from a refining-furnace of 100 tons capacity. Sample No. 1 was taken after melting down the electrolytic copper and skimming the slag. Sample No. 2, taken six hours later, represents set copper. During the following two and a quarter hours of poling, samples Nos. 3 to 11 were taken at fifteen-minute intervals; sample No. 11 is tough-pitch copper. The charge was then cast with the exception of a small amount, which was overpoled until a cast bar upon cooling "threw a worm" or "spewed." A section of this bar formed sample No. 12. Samples Nos. 1 to 10, represented in Figs. 1 to 10, were 3 in. long and 1 in. square, being one-half of the test-bar usually cast during refining. All the surfaces are uneven until tough-pitch copper has approximately been

[9] *Trans.*, xxxiv., 671 to 695 (1904).

reached with Fig. 10. Samples Nos. 1 to 5 show cavities; these disappear with sample No. 6, taken when poling had progressed for forty-five minutes. Samples Nos. 11 and 12, representing tough-pitch and furnace-overpoled copper, are shown in

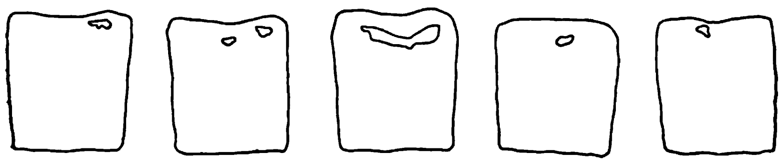


FIG. 1 FIG. 2 FIG. 3 FIG. 4 FIG. 5

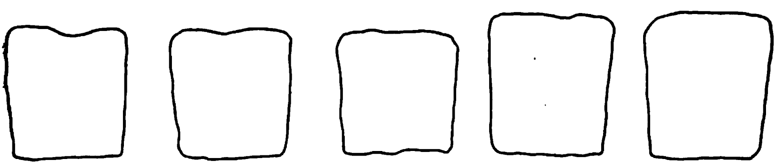


FIG. 6 FIG. 7 FIG. 8 FIG. 9 FIG. 10

FIGS. 1 TO 10.—SAMPLE-BARS OF REFINING-CHARGE NO. 1.

cross-section in Figs. 11 and 12; their photographed surfaces are given in Figs. 13 and 14. The tough-pitch copper has the characteristic wrinkled level surface; the furnace-overpoled copper

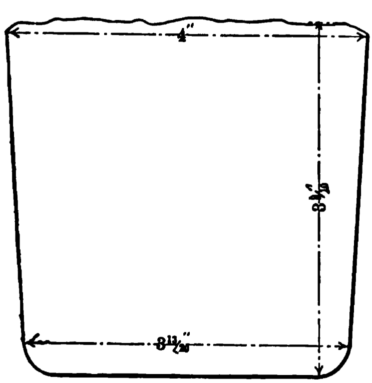


FIG. 11.—CROSS-SECTION OF TOUGH-PITCH WIRE-BAR.

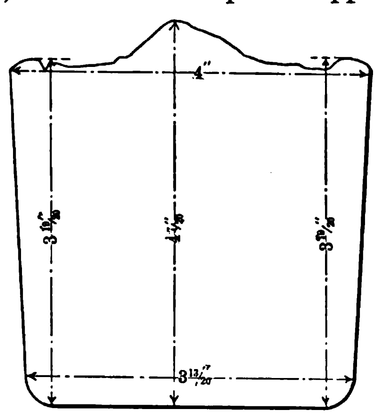


FIG. 12.—CROSS-SECTION OF FURNACE-OVERPOLED WIRE-BAR.

has a rough surface, a large ridge at the center and two small ones at the sides.

(*b*) *Specific Gravity.*—The figures for specific gravity, given in Table I., were calculated from the data obtained in the electrical tests by the formula, spec. gr. $= \frac{w}{Al}$, in which w is the

weight of the wire sample in grams, A the area in square centimeters, and l the length in centimeters.

TABLE I.—*Specific Gravity.*

Sample No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Specific gravity	8.642	8.116	8.466	8.606	8.662	8.787	8.854	8.878	8.889	8.900	8.906	8.824

(*c*) *Tensile Strength and Elongation.*—On account of the form of the samples, the mechanical tests had to be made with specimens drawn into wire. For this purpose, pieces 0.5 by 1 in. and 2.5 in. long were cut from the specimens in such a way as to leave the surfaces of the originals intact. The pieces were drawn to 0.04 in. in diameter, corresponding to No. 18 B. & S. gauge, and then annealed together by a Connecticut brass manufacturing company. Difficulties in drawing were encountered only with samples Nos. 1 to 4, the last drawings of which had to be made by hand. The wires obtained varied in length from 15 to 35 ft., with the exception of that from sample No. 2 (set copper), which gave a length of only 7 ft. The tests were made with a Fairbanks wire-testing machine, the wires used being about 2 ft. long. The averages of the results are assembled in Table II.

TABLE II.—*Tensile Strength and Elongation.*

Sample No.	Tensile Strength.	Elongation in 8 In.
	Lb. per Sq. In.	Per Cent.
1	34,400	29.0
2	29,600	26.6
3	33,520	23.2
4	31,580	8.6
5	34,070	29.7
6	33,320	32.7
7	31,650	33.7
8	31,320	26.1
9	31,900	33.9
10	31,200	30.1
11	30,970	32.2
12	31,650	31.6

(*d*) *Electric Conductivity.*—The tests were made with a Wheatstone bridge, using wire-lengths of about 5 ft. The averages of the results are given in Table III.

Fig. 13.—Tough-Pitch Wire-Bar.

Fig. 14.—Furnace-Overpoled Wire-Bar.

Fig. 19.

Fig. 20.

Figs. 19 and 20.—Surface of Furnace-Overpoled Wire-Bar, Showing Worm.

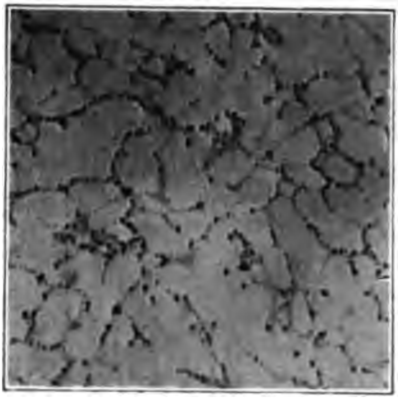


FIG. 25.—TOUGH-PITCH ELECTROLYTIC COPPER.

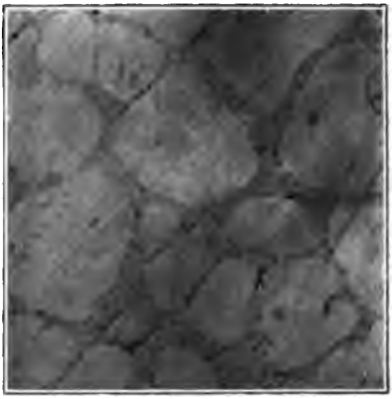


FIG. 26.—FURNACE-OVERPOLED ELECTROLYTIC COPPER.

FIG. 27.—TOUGH-PITCH ELECTROLYTIC COPPER.

FIG. 28.—FURNACE-OVERPOLED ELECTROLYTIC COPPER.

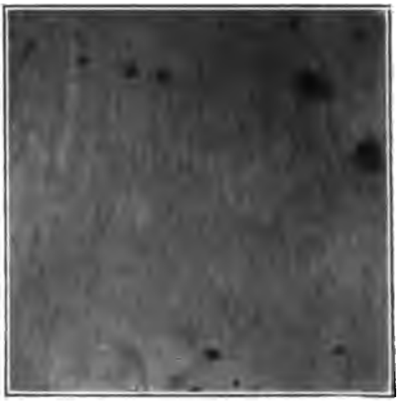


FIG. 29.—CRUCIBLE-OVERPOLED COPPER.

TABLE III.—*Electric Conductivity.*

Sample No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.
Electric conductivity.	98.16	86.61	92.72	94.34	96.27	99.72	101.23	101.15	100.65	101.60	101.36	100.75

(*e*) *Chemical Changes.*—Only the chemical changes relating to copper, iron, sulphur and oxygen were considered. Copper, iron and sulphur were determined by chemical analysis, oxygen by planimetric measurement. All analytical work was carried through according to the methods perfected by G. L. Heath and given in his paper,[10] "Methods for the Complete Analysis of Refined Copper." The wires from the physical tests formed the analytical material. Two separate samples had to be weighed out for the determinations, one for copper and iron, and one for sulphur, as the copper was deposited electrolytically from a sulphuric acid solution. Iron was precipitated from the sulphate solution after this had been freed from copper. In the planimetric measurement of oxygen from enlarged photomicrographs, the mode of procedure given by Hofman, Green and Yerxa[11] was followed. The averages of the results are given in Table IV.

TABLE IV.—*Analytical Results.*

Sample No.	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.
Cu (+ Ag)	99.22	98.12	98.50	99.25	99.52	99.61	99.66	99.70	99.74	99.82	99.87	99.70	....
FeO	0.121	0.086	0.022	0.017	0.016	0.017	0.018	0.016	0.017	0.019	0.020	0.067	0.085
SO_2	....	0.030	0.030	0.029	0.032	0.029	0.028	0.030	0.027	0.027	0.028	0.021	tr.
O Measured planimetrically.	....	....	....	....	....	....	....	....	....	....	0.0119	0.0794	none

(*f*) *Discussion of Data.*—In order to bring out the results more clearly than is convenient in the detached tables, and thus facilitate a review, all the data have been assembled and represented graphically on a single sheet in Fig. 15. Their discussion is confined for the present to samples Nos. 1 to 11, inclusive; samples Nos. 12 and 13, dealing with overpoled copper, will be taken up later.

The copper (plus silver) content, which at the start (sample No. 1) was 99.22 per cent., is seen to fall to 98.12 per cent.,

[10] *Journal of the American Chemical Society,* vol. xxvii., pp. 308 to 318 (1905).

[11] *Trans.*, xxxiv., 671 to 695 (1904).

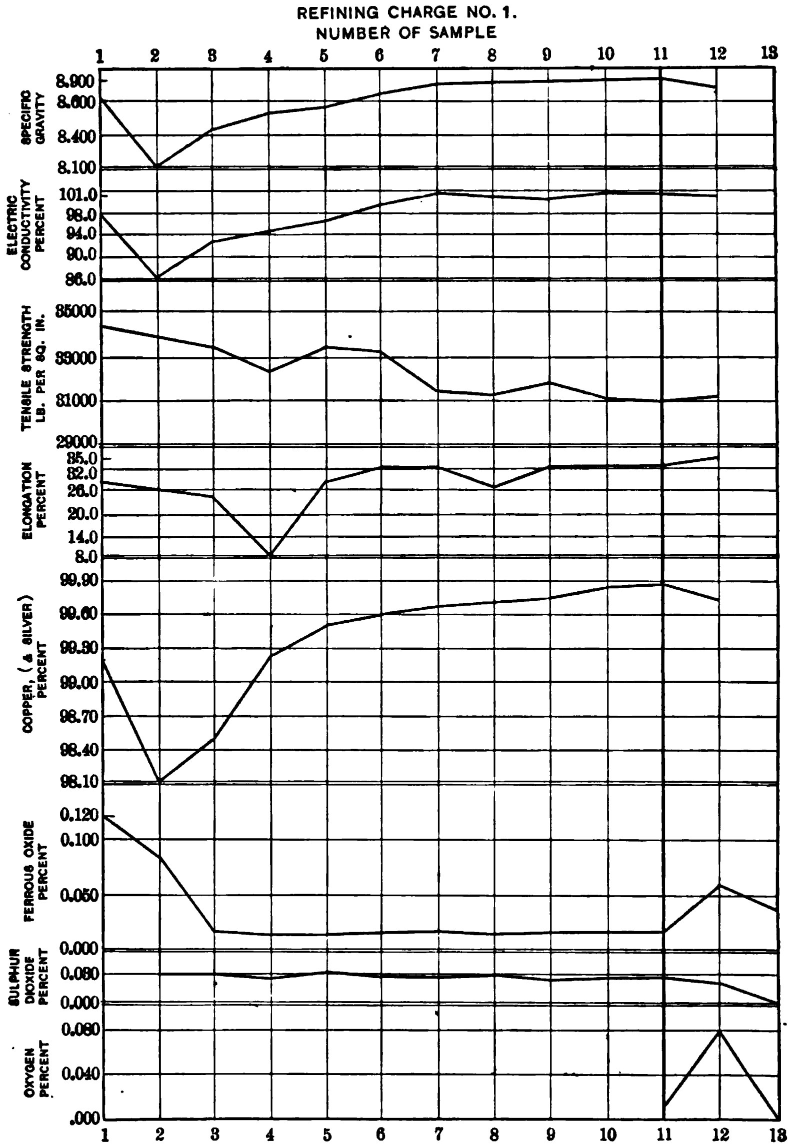


FIG. 15.—PHYSICAL AND CHEMICAL CHANGES OF ELECTROLYTIC COPPER IN REFINING.

when, after oxidation for 6 hr., the stage of set copper (sample No. 2) has been reached. During the first hour of poling the percentage of copper rises quickly, reaching 99.61 per cent. with

sample No. 6, then more slowly, attaining the maximum of 99.87 per cent. with tough-pitch copper (sample No. 11).

Ferrous oxide, usually lower than sulphur, is here higher. It shows a peculiar behavior. It would have been expected that the original 0.121 per cent. would have been slagged off completely during the six hours of oxidizing fusion, but it was reduced with set copper to 0.086 per cent., and only then brought to the minimum of 0.022 per cent. by the first quarter-hour of poling, to remain practically unchanged. The only explanation that suggests itself is that iron was taken up from the pipe through which air was forced into the copper during the oxidizing stage, and that this was quickly expelled when the pipe had been withdrawn and the pole inserted.

While the sulphur-content is high for electrolytic copper, it remains practically constant at 0.030 per cent., the extreme figures being 0.028 and 0.032 per cent. It appears, then, that with electrolytic copper no sulphur is eliminated during the refining operation.

Oxygen determinations were confined to sample No. 11, tough-pitch copper, which contained 0.0119 per cent.

The specific-gravity curve shows the same general trend as that of the copper-content, as was to be expected; starting with 8.642, it reaches the minimum of 8.116 with set copper, and the maximum of 8.906 with tough-pitch copper.

Electric conductivity gives a curve resembling those of copper-content and specific gravity. The electric conductivity, 98.16 per cent. with sample No. 1, reaches its minimum of 86.61 per cent. with set copper (sample No. 2), and then rises to the maximum of 101.23 per cent. with sample No. 7, 1.25 hr. after poling had been started, and remains approximately at that figure for the additional one hour of poling necessary to reach the tough-pitch state. While electric conductivity has become a very important test for judging the physical properties of copper, the curve shows that, at least in the present case, the conductivity-test did not tell the whole story, even though the copper under consideration was a high-grade metal.

The tensile strength of 34,400 lb. of sample No. 1 shows a gradual decrease to 30,970 lb. with tough-pitch copper (sample No. 11). Fluctuations in the curve between samples Nos. 3

and 7 are caused by the difficulty in adjusting the wires, brittle at this stage, in the jaws of the machine.

The elongation increases as the poling progresses; the irregularities are due to the same causes as those of the variations in the tensile-strength tests. Starting with 29 per cent., it reaches a minimum of 8.6 per cent. half an hour after poling has begun, and a maximum of 32.2 per cent. with tough-pitch copper.

2. *Refining-Charge No. 2.*

(*a*) *Samples.*—Fifteen samples, taken from a refining-furnace of 120 tons capacity, were examined to study the changes that took place during the operation. Six samples, Nos. 13 to 18, were small ingots, $4\frac{1}{8}$ in. long by $2\frac{1}{4}$ in. wide at top and $1\frac{15}{16}$ in. wide at bottom by $1\frac{7}{8}$ in. thick. Sample No. 13 represents set copper, sample No. 14 was taken after the first pole had been withdrawn, sample No. 15 after the two subsequent poles had been used up, sample No. 16 after poles 4 and 5 had been taken out, sample No. 17 after poles 6 and 7 had been removed, and sample No. 18 after the copper had reached the tough-pitch stage. The specimen for microscopical examination was taken from the center of a cross-sectional piece cut off from the end of a bar; the material for chemical analysis was obtained by boring five holes $\frac{3}{8}$ in. in diameter into the bottom of a bar, a hole penetrating one-half. The six samples, Nos. 13a to 18a, were duplicates of Nos. 13 to 18, cast into the form of a nail, $5\frac{3}{8}$ in. long and $\frac{5}{8}$ in. in diameter at the top, and 0.5 in. at the bottom. The lower half of a nail was cut off to be drawn into wire for the mechanical and electrical tests. The wires were drawn to No. 18 B. & S. gauge at the works of the American Steel & Wire Co., Worcester, Mass. The drawn wires were annealed together. Difficulties similar to those with the brittle specimens of refining-charge No. 1 were also encountered here. The three samples, Nos. 19 to 21, are sections of full-size wire-bars of furnace-overpoled copper; their contours, shown in Figs. 16 to 18, represent typical crowned surfaces. Figs. 19 and 20 are photographs of the surfaces of two of the samples in which the worm thrown was very pronounced.

(*b*) *Specific Gravity.*—The specimens polished for microscopical examination served for the determinations of the specific

gravity, made in the usual way by weighing in air and in water with the necessary precautions. The data obtained are given in Table V.

TABLE V.—*Specific Gravity.*

Sample No.	13.	14.	15.	16.	17.	18.	19.	20.	21.
Specific gravity.	8.23	8.36	8.47	8.63	8.61	8.69	8.12	8.24	8.58

(*c*) *Tensile Strength and Elongation.*—The mechanical tests were carried out in the same manner and with the same ma-

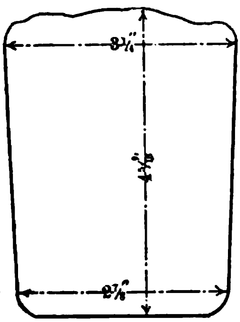


FIG. 16.

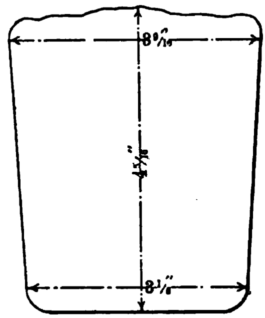


FIG. 17.

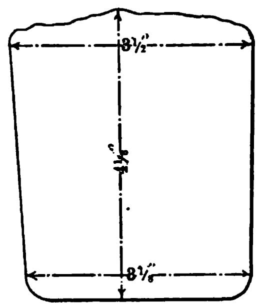


FIG. 18.

FIGS. 16 TO 18.—CROSS-SECTIONS OF FURNACE-OVERPOLED WIRE-BAR.

chine as those of refining-charge No. 1. The results are given in Table VI.

TABLE VI.—*Tensile Strength and Elongation.*

Sample No.	13.	14.	15.	16.	17.	18.	19.	20.	21.
Tensile strength, lb. per sq. in.	39,130	39,020	38,560	37,520	36,630	37,020	35,460	35,720	35,400
Elongation in 10 in., per cent.	34.6	31.2	30.1	31.0	34.2	35.1	34.5	28.2	37.5

(*d*) *Electric Conductivity.*—The tests for electric conductivity were made at the Worcester plant of the American Steel & Wire Co. The figures are assembled in Table VII.

TABLE VII.—*Electric Conductivity.*

Sample No.	13.	14.	15.	16.	17.	18.	19.	20.	21.
Electric conductivity, per cent.	98.2	98.3	98.7	99.6	99.2	99.6	99.8	99.5	100.3

(*e*) *Chemical Changes.*—In addition to following up the changes which take place in the content of copper, iron and sulphur of the metal-bath during refining, planimetric measurements of oxygen were made of all the samples. The results are brought together in Table VIII.

TABLE VIII.—*Chemical Changes.*

Sample No.	13.	14.	15.	16.	17.	18.	19.	20.	21.
Cu (+ Ag)	99.53	99.67	99.79	99.91	99.93	99.94	....	....	....
FeO	0.0063	0.0059	0.0063	0.0057	0.0059	0.0063	....	....	....
SO_2	0 048	0.042	0.045	0.039	0.042	0.043	....	....	....
O	0.211	0.203	0.171	0.073	0.056	0.044	0.033	0.0063	0.018

(*f*) *Discussion of Data.*—The data obtained in examining samples Nos. 13 to 21 are plotted in Fig. 21. The distance on the abscissa between samples Nos. 13 (set copper) and 18 (tough-pitch copper) has been made approximately the same as that between samples Nos. 2 and 11 of Fig.15, which stand for the same limits in the refining of a charge.

The copper (and silver) content, 99.53 per cent., of sample No. 13, is the lowest of the series, as the start was made with set copper. In poling, it rises quickly at first to 99.91 per cent., sample No. 16, and then only very slowly reaches the maximum of 99.94 per cent. with tough-pitch copper, sample No. 18.

The determinations of ferrous oxide gave a range of 0.0057 and 0.0063 per cent., and the curve rises and falls within it without any regularity whatever. This indicates that the iron is not distributed evenly throughout the mass of the bath, and that it is not diminished in amount during the period of poling.

The variations in sulphur dioxide, 0.039 to 0.048 per cent., are greater than those of ferrous oxide, although the largest difference does not exceed 0.009 per cent. Some sulphur is expelled by poling, as set copper contains 0.048 per cent. sulphur dioxide and tough-pitch copper 0.043 per cent., but the amount is insignificant.

The oxygen curve forms an interesting inverse to that of the copper-content The 0.211 per cent. oxygen of set copper decreased quickly with the poling until sample No. 16, with 0.073 per cent. oxygen, was taken, and then slowly, being reduced only 0.029 per cent. when the metal had been brought

to the tough-pitch stage, ready to be cast. The figure of 0.211 per cent. oxygen (= 1.43 per cent. cuprous oxide) for set copper is very low; and would seem to show that with this charge

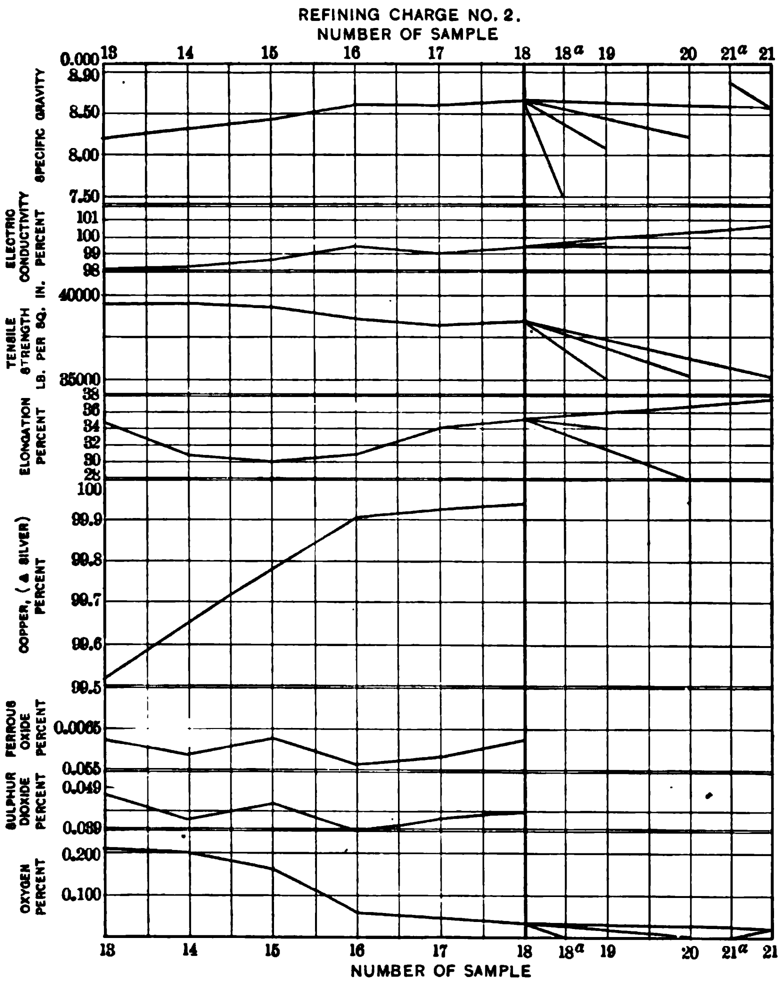


FIG. 21.—PHYSICAL AND CHEMICAL CHANGES OF ELECTROLYTIC COPPER IN REFINING.

the oxidizing fusion had not been carried as far as is common practice.

The specific gravity of the metal increases as the poling progresses, just as did the percentage of copper, more quickly during the first than during the second stage of poling; be-

tween samples Nos. 13 and 16 there is a rise from 8.23 to 8.63, and between samples Nos. 16 and 18 a difference of only 0.06.

The curve of electric conductivity resembles that of copper-content and of specific gravity. Set copper, when annealed, had a conductivity of 98.2 per cent.; this increased at first quickly, reaching 99.6 per cent. with sample No. 16; tough-pitch copper showed no improvement upon this amount.

The tensile strength decreased very little considering the amount of oxygen that had been removed; at the start it was 39,130 lb., at the finish 35,400 lb.; the fall in tenacity is more gradual and regular than was expected.

The data for elongation are irregular. There is a fall from 34.6 to 30.1 per cent., then a rise of a similar amount to 34.2 per cent., followed by a slight increase to 35.1 per cent. It was expected that the elongation would increase with the elimination of oxygen.

3. *Summary of Refining-Charges Nos.* 1 *and* 2.

The two charges examined were electrolytic copper from the multiple process; they represented a high-grade metal and were refined in reverberatory furnaces of similar construction and capacity, and by the usual method of oxidizing with compressed air and reducing with the use of poles. It was therefore to be expected that the changes the metal underwent in poling would be similar. A comparison of the curves in Figs. 15 and 21 proves this to be the case. The percentage of copper rises quickly at first and at about the same rate as the cuprous oxide is reduced; later it increases more slowly as it becomes more difficult to deoxidize the remaining small amounts of cuprous oxide to just the quantity that has to remain with the tough-pitch copper. The amount of ferrous oxide present in electrolytic copper is very small; any excess over a minimum, varying with different charges, is quickly eliminated. The sulphur-content of electrolytic copper remains practically unchanged in fire-refining. The specific gravity and electric conductivity rise and fall with the copper-content; cuprous oxide has an effect opposite to that of copper. The tensile strength decreases as the reduction of cuprous oxide progresses; the corresponding increase in elongation is not shown as clearly by the curves as was expected.

III. Studies in Overpoling Electrolytic Copper.

The current meaning of the term, copper overpoled in the reverberatory furnace, is that poling has been carried beyond the tough-pitch stage, with the result that the reduction has been carried too far, causing the copper to become porous and brittle, and thus unfit for industrial purposes. It will be shown that the brittleness of furnace-overpoled electrolytic copper must generally be attributed to other causes than over-reduction. The present investigation, dealing with such pure metal as electrolytic copper, excluded the consideration of the effects that elements like arsenic, antimony, lead, bismuth, nickel, etc., might have if present in the oxidized or the metallic state; it confined itself to the remaining active agents, cuprous oxide, gases and temperatures, and incidentally to sulphur and iron. The plan of work was to examine samples of tough-pitch and furnace-overpoled copper from the same charges as obtained from works, to eliminate all the oxygen from the tough-pitch copper by reduction in a crucible, and to compare the results.

(*a*) *Samples.*—In addition to the samples from the two refining-charges (Nos. VIII. and IX., Table IX.) discussed in the first part of this paper, there were examined five specimens of electrolytic copper from Eastern works (samples Nos. I., III., IV., V., VI.), one of casting-copper (sample No. VII.), and one of native copper (sample No. X.). The samples (Table IX.) are marked with Roman numerals; the letter A affixed to a numeral designates the sample as tough-pitch copper furnace-overpoled at the works, the letter B as tough-pitch copper crucible-overpoled in the experiments. The results are assembled in Tables IX and X. Further data in regard to furnace-overpoling are given in Table XI., in which have been brought together some facts of an experimental run made by a Western plant in 1899 with a charge of 27.5 tons of cathode copper. The charge was brought to the tough-pitch stage in the usual way, overpoled, rabbled again to convert the overpoled copper into set copper, poled to tough-pitch copper, and again overpoled.

(*b*) *Crucible-Overpoling.*—The object of overpoling in a crucible was to eliminate by means of charcoal and by the exclusion of air all the oxygen of a sample and thus obtain what may be

termed true overpoled copper. The apparatus used is shown in Fig. 22. The reducing crucible, *A*, was made of Acheson graphite, which is practically free from impurities. The cavity, $\frac{13}{16}$ in. in diameter and 3.5 in. deep, was bored into a stick 1.5 in. in diameter and 4 in. long. The graphite crucible was placed in a G fire-clay crucible, *B*, packed with crushed fire-brick, *C*, the tops of the graphite crucible and packing were covered with a layer of charcoal, *D*, 0.5 to 0.75 in. deep, and the clay crucible closed with a lid. Filings and chippings from

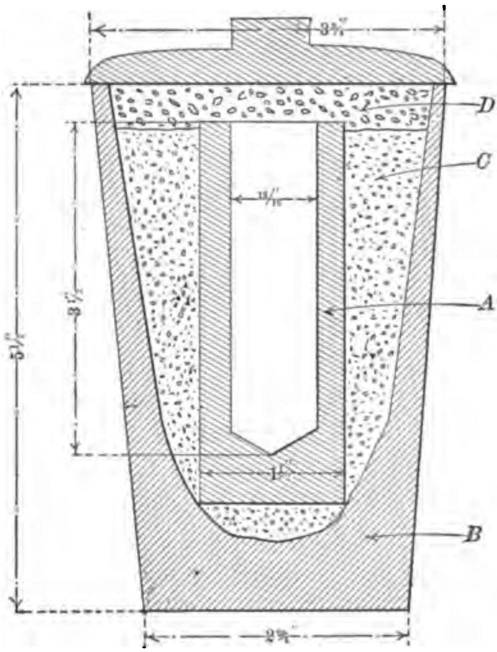


FIG. 22.—APPARATUS FOR CRUCIBLE-OVERPOLING.

tough-pitch copper were charged, and the apparatus then placed in a pot-furnace. When the charges had been fused, more copper was added to about fill the graphite crucible, the layer of charcoal spread over it, the copper kept molten about 15 min., the apparatus removed from the furnace, and allowed to cool slowly with a layer of charcoal still on top of the copper. When cold, the copper cylinder could be easily removed. A graphite crucible was found to stand 4 or 5 heatings without cracking. As air was not wholly excluded at first during the melting-down of the copper, the upper edge of the graphite crucible was

TABLE IX.—*Record of Experiments.*

Kind of Copper.	No. of Sample	Physical Properties.							Chemical Composition.				
		Surface.	Resistance to Breaking	Appearance of Fracture.			Specific Gravity.	Electrical Conductivity.	Cu (+ Ag).	FeO.	SO_3.	Sulphide Sulphur.	O.
				Texture.	Luster.	Color.			Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Tough-pitch, electrolytic	I.	Even.	Very tough	Hackly.	Silky.	Rose.	8.666	99.6	99.819	0.004	0.017	....	some.
Furnace-overpoled, electrolytic	IA.	Even, crowned.	Brittle.	Fine granular to vesicular.	Dull.	Light brick-red.	8.680	99.6	99.770	0.005	0.0038	present.	> I.
Crucible-overpoled, electrolytic	IB.	Flat, rough, cavity.	Tough.	Fibrous to hackly.	Half-silky.	Rose to light salmon.	9.043	98.92	....	....	....	....	none.
Tough-pitch, electrolytic	III.	Even.	Very tough	Hackly.	Silky.	Rose.	8.630	99.81	99.920	trace.	0.016	....	some.
Crucible-overpoled, electrolytic	IIIB.	Crowned, cavity.	Tough.	Hackly to cubical.	Glimmering.	Light salmon to rose.	8.881	98.5	....	....	....	present.	none.
Tough-pitch, electrolytic	IV.	Even.	Very tough	Hackly.	Silky.	Rose.	8.586	100.57	99.942	0.029	0.020	....	considerable.
Crucible-overpoled, electrolytic	IVB.	Crowned, cavity.	Very tough	Hackly.	Shining.	Rose to light salmon.	8.933	99.8	....	....	....	absent.	none.
Tough-pitch, electrolytic	V.	Even.	Very tough	Hackly.	Silky.	Rose.	8.806	98.6	99.938	0.019	trace.	....	some.
Crucible-overpoled, electrolytic	VB.	Crowned, cavity.	Very tough	Hackly to radiating.	Shining.	Rose to light salmon.	8.855	98.1	....	....	....	absent.	none.
Tough-pitch, electrolytic	VI.	Even.	Very tough	Hackly.	Silky.	Rose.	8.550	100.0	99.889	trace.	0.013	....	some.
Furnace-overpoled, electrolytic	VIA.	Smooth.	Very brittle	Finely granular.	Dull.	Light brick-red.	8.407	99.08	99.771	0.011	trace.	....	> VI.
Crucible-overpoled, electrolytic	VIB.	Flat, rough, cavity.	Very tough	Hackly.	Shining.	Rose to light salmon	8.950	99.6	....	....	....	absent.	none.
Tough-pitch, casting	VII.	Even.	Very tough	Hackly.	Silky.	Rose.	8.548	92.8	99.794	0.011	0.013	....	some.
Crucible-overpoled, casting	VIIB.	Uneven, cavity.	Tough.	Hackly to slightly gran.	Dull.	Light salmon to rose.	8.930	98.5	....	....	....	absent.	none.
Tough-pitch, electrolytic	VIII.	Even.	Very tough	Hackly.	Silky.	Rose.	8.547	99.6	99.952	0.023	0.013	....	0.044
Furnace-overpoled, electrolytic	VIIIA.	Ridge.	Brittle.	Finely granular.	Dull.	Light brick-red.	8.240	99.8	....	0.032	0.014	....	0.063
Crucible-overpoled, electrolytic	VIIIB.	Crowned.	Tough.	Hackly to columnar.	Glimmering.	Rose to light salmon.	9.036	99.3	....	....	....	absent.	none.
Tough-pitch, electrolytic	IX.	Even.	Very tough	Hackly.	Silky.	Rose.	8.906	101.3	99.87	0.019	0.028	....	0.0119
Furnace-overpoled, electrolytic	IXA.	Ridge.	Brittle.	Finely granular.	Dull.	Light brick-red.	8.824	100.7	99.70	0.058	0.021	....	0.0794
Crucible-overpoled, electrolytic	IXB.	Crowned, cavity.	Tough.	Vesicular.	Bright.	Yellow.	....	....	....	0.085	....	present.	none.
Native copper	X.	....	Very tough	Hackly.	Bright.	Rose.	8.830	102.5	99.960	0.0055 Fe.	none.	absent.	none.

slightly burnt away. The entire absence of oxygen from the overpoled copper shows that the charcoal cover added had reduced any surface-oxidation of the charge that might have taken place. In melting down the first sample of tough-pitch copper, charcoal was charged with the copper. It was found, however, that some of the finer particles did not rise to the surface and made the copper cylinder rough and pitted. The main results are given in Table IX.; additional details of the tests are recorded in Table X.

TABLE X.—*Crucible-Overpoled Copper.*

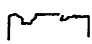
Sample No.	Diameter.	Length.	Weight.	Surface.	Cavities, No. and Location.	Fern-like Crystals.	Vertical Section Through Copper Cylinder.
	Inch.	In.	Grams.				
IB	13/16	2 7/16	162	Flat, rough.	2 in top.	Indistinct.	
IIIB	13/16	2 5/8	165	Crowned.	1 in side.	Numerous.	
IVB	13/16	2 3/4	180	Crowned.	1 in top.	Few.	
VB	13/16	2 13/16	185	Crowned.	1 in side.	Numerous.	
VIB	13/16	2 5/8	152	Flat, rough.	1 in top.	Numerous.	
VIIB	13/16	2 1/2	170	Uneven.	1 in top,	Numerous.	
VIIIB	13/16	2 5/8	197	Crowned.	Not clearly defined.	Indistinct.	
IXB	13/16	2 3/4	170	Crowned.	1 in top.	Numerous.	

Table IX. shows that some samples of crucible-overpoled copper contain sulphide-sulphur. Its presence was determined by etching a polished sample with hydrofluoric acid. Under the microscope both cuprous oxide and cuprous sulphide show a bluish color, but, as first shown by Heyn,[12] etching with hydrofluoric acid colors cuprous oxide black and leaves cuprous sulphide unchanged, thus making it easy to distinguish them from one another. Fig. 29 represents crucible-overpoled copper free from oxygen, with black spots of cuprous sulphide. In the experiments, Baker and Adamson's c.p. hydrofluoric acid was used; 5 seconds' treatment was sufficient to change cuprous oxide from blue to black. Attention may be called to

[12] *Metallurgie*, vol. iii., p. 73 (1906).

TABLE XI.—*Refining-Experiments in Reverberatory Furnace.*

Operations, December, 1899, on 27.5 Tons Cathode Copper.			Sample.		Physical Changes.				Chemical Changes.		
Character.	Time Given. Hr. and Min.	Temperature. °C.	Number.	Description.	Electric Conductivity, No. 12 B. & S. Gauge, Hard Drawn.	Tensile Strength. Lb. Per Sq. In.	Elongation in 5 Feet.	Torsion in 6 Inches.	As and Sb.	O.	S.
							Per Ct.				
Melting and skimming	8.50	....	1	Skimmed copper.	could	not be	drawn.	....	0.0068	0.352	0.0202
Rabbling	1.50	1,130	2	Set copper.	could	not be	drawn.	....	....	0.546	0.0078
Tough-poling	1.30	1,170	3	Tough-pitch copper.	96.57	65,400	1.1	80	0.0060	0.071	0.0066
Overpoling	1.05	1,190	4(a)	Overpoled copper, median line.	could	not be	drawn.	....	....	0.0609	0.0077
Overpoling	0.15	1,115	5(b)	Overpoled copper, spew.	96.00	65,000	1.1	32	....	0.0540	0.0082
Rabbling	1.35	1,117 aver., 1,030 finish.	6(c)	Set copper.	could	not be	drawn.	....	......	0.481	0.0060
Tough-poling	1.25	1,120 aver., 1,155 finish.	7	Tough-pitch copper.	96.36	65,900	1.1	30	0.0070	0.058	0.0044
Dipping 86 bars, adding charcoal and brands	1.00	1,145	8	Tough-pitch copper.	96.13	66,600	1.2	27	....	0.073	0.0044
Dipping 26 bars, adding charcoal and brands	0.28	1,120	9	Overpoled copper, crown.	96.10	66,500	1.2	28	....	0.0506	0.0055
Overpoling	0.23	1,110	10	Overpoled copper, median ridge.	96.46	66,400	1.2	42	....	0.0445	0.0087
Overpoling	0.05	1,130	11	Overpoled copper, spew.	96.48	66,700	1.1	42	0.0057	0.048	0.0103

(*a*) Between samples 4 and 5, charcoal raked off, air admitted, fresh coal added to fire.
(*b*) Between samples 5 and 7, charcoal raked off, fresh fire made on grate.
(*c*) Metal too cold, adheres to poles; poles removed, fresh fire made, and poling started again.

the fact that Hampe[13] had ascertained long ago by analytical methods that cuprous oxide, cuprous sulphide and sulphur dioxide could be present together in tough-pitch copper.

The terms used in Table IX. to denote resistance to breaking require to be more closely specified. In breaking with a hammer a nicked sample clamped in a vise, the sample was termed very brittle when 1 blow was sufficient to break it, brittle when 3 or 4 blows were required, tough with more than 4 blows striking on one side, very tough with more than 4 blows striking on both sides.

The formation of a cavity when copper free from cuprous oxide is fused and cooled under reducing conditions, is a phenomenon to be expected, as copper shrinks upon cooling. Casting a bar of copper 3 by 3 by 30 in. on end with exclusion of air, J. B. Cooper[14] obtained a pipe 5 in. deep, as shown in Fig. 23. When air came in contact with the surface of such a bar, when partly solidified, the surface rose immediately and finally crowned. The cross-section of such a bar, Fig. 24, 7 in. beneath the top, showed a core about 1 in. in diameter, which was crystalline and porous, while the balance was solid, resembling native copper.

A similar experience is that of Percy[15]: Electrolytic copper melted under charcoal in a crucible and left to solidify therein showed no rise, but a depression. Similar copper melted under charcoal and poured, without taking any precautions to exclude air, gave a crowned surface.

While the samples used in the present experiments, weighing 162 to 190 g., did contain some cuprous oxide, and while its percentage may have been slightly increased during the first stage of fusion before the charcoal cover had been given, the microscopic examination of the specimens, which remained fused for 15 minutes under a charcoal cover and cooled in the crucible under it, showed that no cuprous oxide was present, and that therefore the reduction by charcoal had been complete. This is further brought out by the decrease in electric conductivity (see Table IX.) of all the high-grade samples of tough-pitch copper by crucible-overpoling, which must have re-

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[13] *Op. cit.*, vol. xxi., p. 278 (1893).

[14] Private communication, September 3, 1905.

[15] *Metallurgy; Fuel, Fire-Clays, Copper, Zinc, Brass*, etc., pp. 275, 276 (1861).

duced any oxide impurities present to the metallic state. A cavity was to be expected in the metal free from oxide, but the surfaces of all but one specimen (see Table X.) are also crowned. Crowning is due to the evolution of gases. That part of the gases held in solution by the tough-pitch copper have been completely eliminated in crucible-overpoling with the reduction of cuprous oxide and have not left the crucible-overpoled copper porous, is seen (Table IX.) by the rise in specific gravity of all the specimens from tough-pitch to crucible-overpoled copper. The samples of crucible-overpoled electrolytic copper then

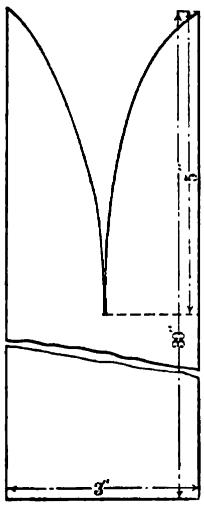

FIG. 23.—VERTICAL SECTION OF BAR CAST UPRIGHT UNDER REDUCING CONDITIONS.

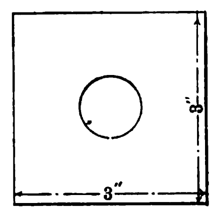

FIG. 24.—HORIZONTAL SECTION OF BAR, FIG. 23, AIR ADMITTED WHEN PARTLY SOLIDIFIED.

present the combination of a cavity due to cooling and a crown due to the evolution of gas.

Crucible-overpoled copper and native copper have only this in common, that they are both free from oxygen.

(*c*) *Furnace-Overpoling.*—When tough-pitch copper is cast from the reverberatory furnace into a mold, it gives an ingot, bar or cake with a level surface; when its surface shows a slight crowning, a ridge, or throws a worm (spews), it is sure to be overpoled. As shown above, the rising of the surface is due to the giving off of gas. Hampe[16] found that copper had the

[16] *Zeitschrift für Berg-, Hütten- und Salinen-Wesen in Preussen*, vol. xxi., p. 274 (1873).

property of absorbing sulphur dioxide, hydrogen and carbon monoxide, which rendered the metal porous. By heating copper charged with soluble gas in a current of carbon dioxide, which is insoluble, he expelled the dissolved gas and obtained a dense metal with a correspondingly higher specific gravity. Thus[17] he raised the specific gravity of copper from Mansfeld, containing 0.075 per cent. of oxygen, from 8.525 to 8.906 by fusing in a current of carbon dioxide, the chemical composition of the metal remaining unaffected.

Caron[18] had proved before Hampe that fused copper had the property of absorbing hydrogen and carbon monoxide.

Stein[19] recovered from porous copper by gently heating in vacuo first hydrogen, then carbon monoxide. Heyn[20] found that copper heated in a current of hydrogen to 600° C., became brittle and showed a decrease in specific gravity. Stahl[21] examined three samples of slightly overpoled copper free from sulphur, taken from reverberatory-furnace charges just before casting. With a copper-content of 99.924, 99.893 and 99.899 per cent., the specific gravity was, 8.342, 8.466 and 8.266, while the specific gravity of the tough-pitch copper of the works averaged over 8.900.

Perhaps the most striking examples of gas-absorption by copper while being poled are those shown in Table XII., given by Stahl,[22] which show a decrease of oxygen with a decrease of specific gravity, while just the reverse would have taken place had it not been for the gas-absorption.

In poling, the charring of the wood sets free water-vapor, which stirs the copper, and carbon monoxide, hydrogen and hydrocarbons, which become more or less disseminated through it. As long as the copper is heavily charged with cuprous oxide, carbon monoxide and hydrogen cannot be retained by the copper, as they are oxidized to carbon dioxide and water-vapor, which are insoluble in copper; hydrocarbons are decom-

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[17] *Op. cit.*, vol. xxii., p. 131 (1874.)

[18] *Comptes rendus*, vol. lxiii., p. 1129 (1866); *Dingler Polytechnisches Journal*, vol. clxxxiii., p. 384 (1867).

[19] *Berg- und Hüttenmännische Zeitung*, vol. xl., p. 235 (1881).

[20] *Zeitschrift des Vereines deutscher Ingenieure*, vol. xliv., p. 508 (1900).

[21] *Ueber Raffination, Analyse und Eigenschaften des Kupfers*, Fiske, Altenau i. Harz, p. 52 (1886).

[22] *Op. cit.*, p. 55.

TABLE XII.—*Effect of Dissolved Gas upon Specific Gravity of Copper.*

Charge No.	State of Copper.	Cu.	O.	Specific Gravity.
		Per Cent.	Per Cent.	
	Dense-poled (*a*).	....	0.210	8.916
1	Tough-poled, ½ hour.	....	0.123	8.851
	Tough-poled, 1¼ hours.	99 882	0.086	8.713
	Dense-poled (*a*).	....	0.186	8.895
2	Tough-poled, ¼ hour.	....	0.164	8.887
	Tough-poled, 1 hour.	99.860	0.078	8.684
	Dense-poled (*a*).	....	0.198	8.903
	Tough-poled, ¾ hour.	....	0.102	8.704
3	Tough-poled, 1¾ hours.	....	0.051	8.405
	Reoxidized.	99.776	0.209	8.907

(*a*) Dense-poling, which is common in German practice, means poling under partly oxidizing conditions with the object of expelling dissolved sulphur dioxide; it precedes tough-poling.

posed, the hydrogen is first oxidized and then the carbon. As the percentage of cuprous oxide decreases in poling, the oxidation of the gases diminishes, the absorption of carbon monoxide and hydrogen increases, and the finely-divided carbon from the decomposed hydrocarbons rises unoxidized to the surface of the metal bath. The absorbing power of copper for gas increases with the temperature and the purity of the copper. According to Stahl,[23] the gas-absorption becomes evident before the oxygen of the copper has been reduced to 0.07 per cent.; in one instance he noticed it when the copper still contained 0.160 per cent. of oxygen. Hampe[24] found that the presence of the usual small amounts of impurity in copper did not affect the solubility of hydrogen, that the carbon monoxide was less soluble than hydrogen, and that cuprous oxide had no influence on the solubility of sulphur dioxide. Stahl's experiments[25] proved that lead, arsenic and phosphorus in amounts larger than common in refined copper decreased its dissolving power for gas; thus the addition of about 0.25 per cent. of lead or 0.4 + per cent. of arsenic or 0.024 per cent. of phosphorus toughened porous copper sufficiently to permit its being hammered, rolled or drawn.

[23] *Op. cit.*, p. 47; also, *Berg- und Hüttenmännische Zeitung*, vol. xlviii., p. 323 (1889); vol. lx., p. 77 (1901).

[24] *Zeitschrift für Berg-, Hütten- und Salinenwesen in Preussen*, vol. xxi., p. 274 (1873).

[25] *Op. cit.*, p. 59.

The next question to be considered is, how does furnace-overpoled electrolytic copper differ chemically from tough-pitch electrolytic copper.

As to the oxygen-content, the data in Table IX. show that furnace-overpoled copper may have a higher or a lower percentage of oxygen than the corresponding tough-pitch copper. Thus, examples IA (Fig. 26), VIA and IXA (Fig. 28) contain more, and sample VIIIA less oxygen than the corresponding samples of tough-pitch copper I. (Fig. 25), VI., IX. (Fig. 27) and VIII. In Fig. 21, representing graphically the changes of sample No. VIII. (Table IX.), the tough-pitch copper, No. 18, was furnace-overpoled and three bars were cast at short intervals, giving specimens marked Nos. 19, 20 and 21, all of which contain less oxygen than No. 18. Crucible-overpoling Nos. 18 and 21 eliminated all the oxygen, as seen by Nos. 18a and 21a. In Table XI., the two furnace-overpoled samples contain less oxygen than the corresponding tough-pitch copper. Thus, of the six samples of furnace-overpoled copper, three contain more and three less oxygen than the respective tough-pitch copper. Refiners[26] hold that most furnace-overpoled copper represents a false-overpole—*i. e.*, the oxygen-content has been raised. Nevertheless, it is not an uncommon practice to slightly rabble copper that shows signs of crowning or tendencies to spewing in order to correct the evil. The rabbling increases the oxygen-content of the copper and thus diminishes its dissolving power for gas This practice is in line with the facts recorded above, in regard to the solubility of gas in copper.

As to the sulphur-content, Table IX. gives three samples of furnace-overpoled copper with a lower (IA, VIA, IXA) and one with a higher (VIIIA) percentage of sulphur than the corresponding tough-pitch copper (I, VI, IX, VIII). In Table XI., the four analyses of furnace-overpoled copper give more sulphur than the two of tough-pitch copper.

In regard to iron, Table IX. shows that the four samples of furnace-overpoled copper contain more iron than the tough-pitch copper. Why this should be so is not clear.

The influence of temperature is not definitely settled by the

[26] J. A. Cooper, private communication, December 13, 1905 ; Addicks, *Journal of the Franklin Institute*, vol. clx., pp. 421 to 433 (1905); *Electrochemical and Metallurgical Industry*, vol. iv., p. 16 (1906).

evidence of Table XI. In the first test, the temperature of the metal bath rose during the 1 hr. 5 min. of overpoling from 1,170 to 1,190° C., the copper became overcharged with gases and showed a median line when cast in a bar; air was then admitted (which did not increase the percentage of cuprous oxide) and coal added to the fire, when after 15 minutes' additional poling at a temperature of 1,115° C., a bar cast spewed upon solidifying. These facts seem to prove that a temperature of 1,115° C. is sufficiently high for copper overpoled for 1 hr. 20 min. to hold enough excess-gas to make it spew upon solidifying when cast in the form of a bar.

In the second test, the copper, 1 hr. 51 min. after the tough-pitch stage, showed a ridge and then required only 5 minutes' poling at a temperature 20° C. higher than before to throw a worm.

The two periods of overpoling, 1 hr. 20 min. and 1 hr. 50 min., of course, are excessively long, as under normal conditions from 5 to 10 minutes is sufficient to spoil the pitch.

IV. Conclusion.

The evidence obtained as to oxygen-, sulphur-, and iron-content of furnace-overpoled electrolytic copper, and as to effect of temperature, does not point clearly in a single direction and permits various interpretations. There remain, however, as undisputed facts, that copper absorbs hydrogen, carbon monoxide and sulphur dioxide, and that the solubility increases with the temperature and decreases with the oxygen-content. With set copper the solubility of the gas is at a minimum on account of the low temperature and the high percentage of the oxygen of the metal bath, and set copper solidifies with depressed surface. With crucible-overpoled copper the solubility is at a maximum on account of the necessarily high temperature and the entire absence of oxygen.

Between these two extremes lies the level set or proper pitch of tough-pitch copper. The proper pitch then appears to be the resultant of the hollow pitch of set copper and the crowned pitch of overpoled copper, and to vary, independently of small admixtures of sulphur and iron, with the size of the casting; a heavy cake holding more gas requires a copper richer in oxygen to counteract the raising power of the gas than does a wire-bar.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The White Knob Copper Deposits, Mackay, Idaho.

BY J. F. KEMP, NEW YORK, N. Y., AND C. G. GUNTHER, CLIFTON, ARIZ.

(New York Meeting, April, 1907.)

I. INTRODUCTION.

THE White Knob copper-deposits are situated about three miles south of Mackay, on the Salmon River branch of the Oregon Short Line Railroad, in Custer county, Idaho. An outline-map of this district is given in Fig. 1. The deposits have been known and spasmodically worked for many years, and a total of over 3.5 miles of tunnels, shafts and other workings has been driven with a view to their development. These extensive excavations have exposed the deposits sufficiently to permit a careful geological examination.

The peculiar features which give special interest to this paper are the branching, tree-like form of the ore-bodies; the absence of zones of secondary enrichment in the partly oxidized pyritic deposits, and the fact that while the deposits are associated in a general way with the contact of an eruptive rock with limestone, which it penetrates, the garnetization has taken place not in the limestone, as is the usual case, but in the igneous

rock itself. Contact zones in the limestones practically fail. A new type of ore-body is thus afforded.

The field-work on which this paper is based was done by Mr. C. G. Gunther during a residence of two years at the mine. Much assistance and advice was received from Mr. W. L. Austin, who is thoroughly familiar with the mines and to whom the writers are indebted for the suggestion of the method of formation subsequently advocated. The notes, collections and maps have been worked up in the laboratory by Prof. J. F. Kemp.

II. Topographical Features of the Region.

Lost River valley, in which the town of Mackay lies, runs in an easterly direction, and is flanked on either side by ranges of

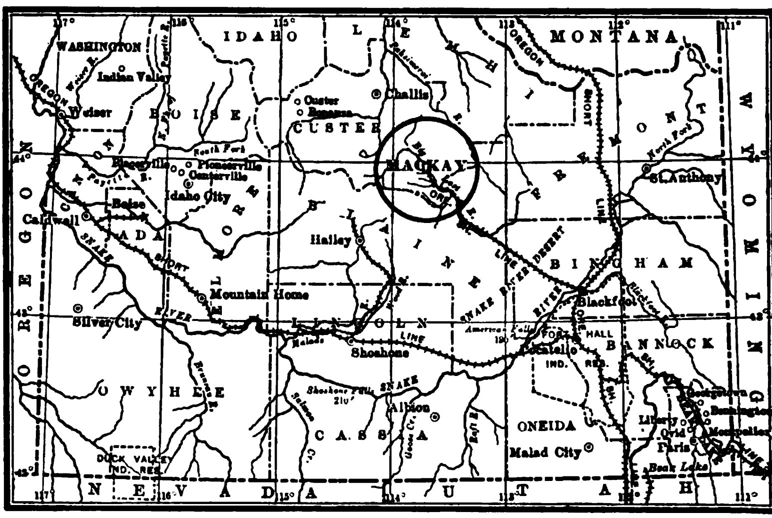

Fig. 1.—Outline-Map of Southern Idaho, Showing the Location of Mackay.

lofty mountains. Lost river itself rises in a spur of the Salmon River mountains and flows easterly, finally disappearing at the mouth of the valley under the lava-beds of the great Snake River flow, as shown in Fig. 1.

The mountains to the north, comprising the Lost River range, consist largely of sedimentary rocks; no discoveries of ores have been reported from them and but little is known of their geological features. The range rising to the south of the valley, termed locally the "Saw Tooth," appears to consist principally of a core of granitic rocks flanked by limestones.

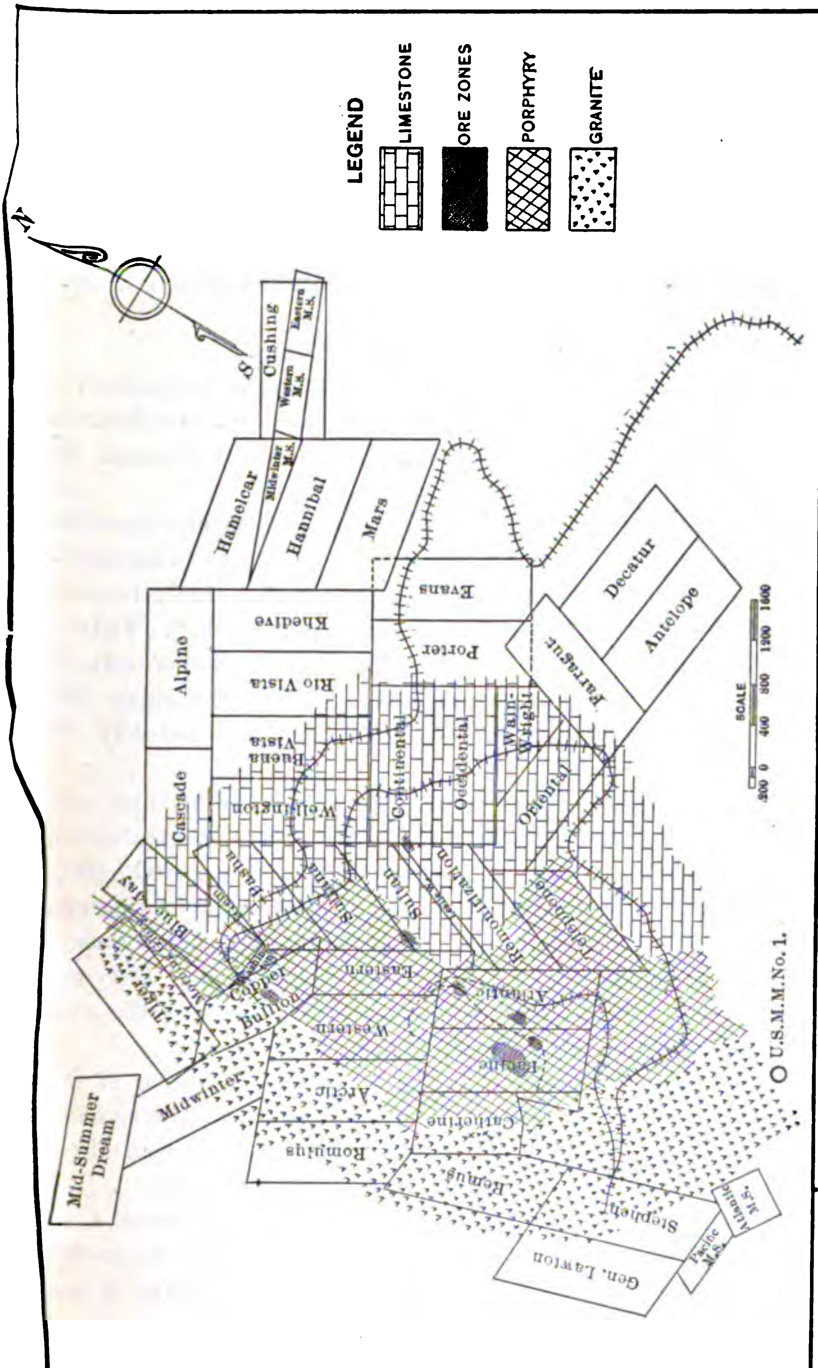

FIG. 2.—SURFACE-MAP OF THE CLAIMS AND GEOLOGICAL FORMATIONS.

In the vicinity of the mines the topography is varied and accentuated. The granite on the southwest, as shown on the geological map, Fig. 3, forms the highest ground. Between it and the limestone is the belt of ore-bearing porphyry, which has weathered readily and has yielded gentle slopes. The limestone is more rugged and has produced a prominent ridge by its resistance to erosion.

III. Geological Relations of the Mineralized Area.

1. *Structural Features.*

The ore-bearing porphyry varies in width from its maximum of 1,500 ft., in the central portion of its exposure, to a decreasing cross-section at its extremities. In amount it is much less than either the granite or the limestone.

The granite, which on the surface outcrops several hundred feet south of the main shaft, extends on the lower tunnel level for several hundred feet north of the foot of this shaft, showing the fundamental position of the rock at this point. This is well illustrated by the section, Fig. 5, which, however, not being taken on a north and south line, represents the upper contact of the granite as having a slighter dip than is actually the case.

Several dikes of trachyte course through the limestone and the quartz-porphyry, but are not known to have penetrated the granite to any great extent. These dikes are approximately parallel, striking a few degrees north of east; their outcrops are with difficulty traceable on the surface, and for this reason have not been shown on the surface-map, Fig. 2. They are well exposed in the mine, however, and are shown on the geological map of the 700 ft.-level, Fig. 4.

At the point marked "3," Fig. 3, a dike or tongue of the quartz-porphyry extends into the limestone; a shaft was sunk at this point from which a little cupriferous material was taken. The copper appears to have been confined to the dike.

In the neighborhood of the large quarry, marked 4 on the geological-map, Fig. 3, there are large masses of magnetite scattered over the hillside, left by the weathering away of the softer country rock, the quartz-porphyry.

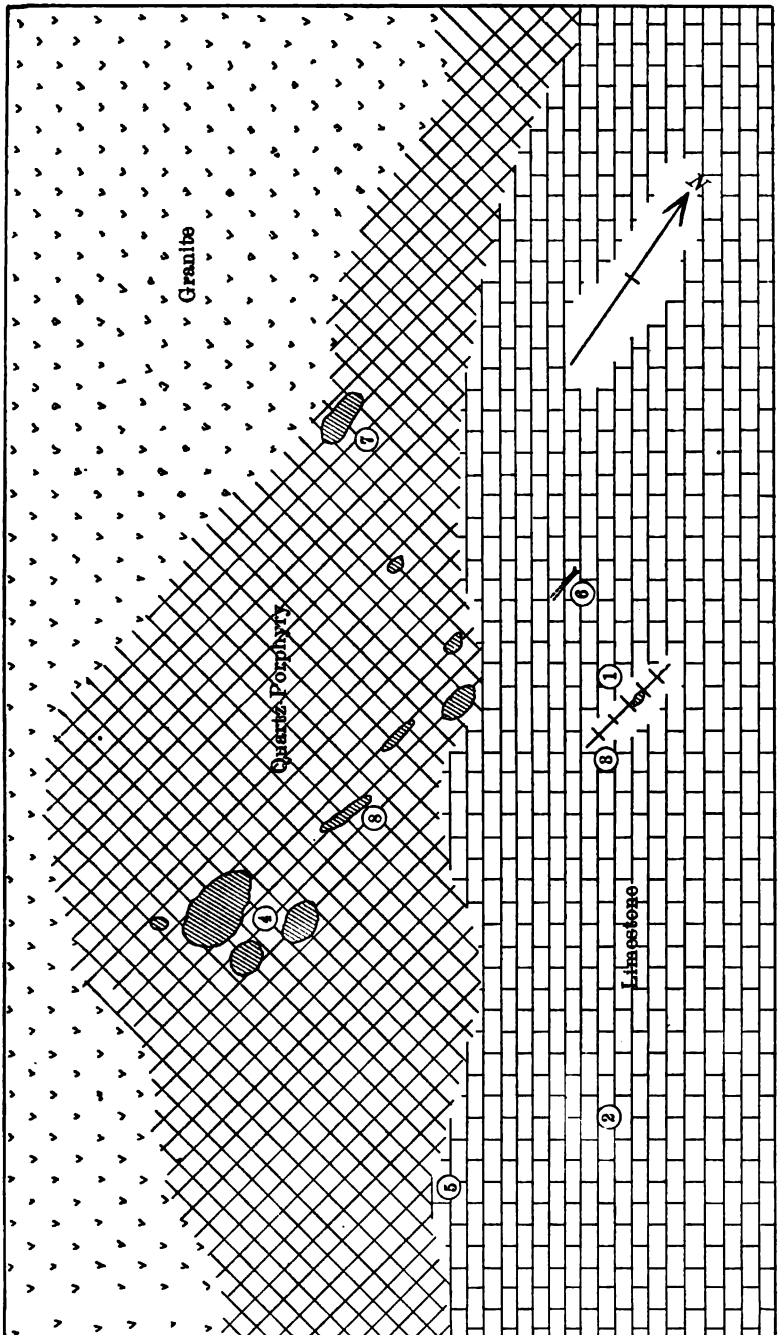

FIG. 3.—GEOLOGICAL MAP OF SHOOTS OF GARNET-ROCK AND PRINCIPAL FORMATIONS. THE SCALE IS 1 IN. EQUAL TO 200 FT., VERY NEARLY.

2. *Occurrence of the Copper.*

The copper ore-bodies are found solely within the area of the quartz-porphyry; instances of their occurrence in the other rocks are wanting.

The porphyry does not carry copper throughout, the mineralization occurring in irregular and unconnected masses limited in area, but apparently continuous to unknown depths These mineralized channels or chimneys occur with greatest frequency within 300 ft. of the limestone contact, but the largest separate mineralized area is found rather nearer the granite than the limestone.

The outcrops of the mineralized portions of the eruptive as developed are shown on the surface-map, Fig. 2, where they are represented by the shaded areas.

3. *Granite-Contacts.*

The contact of the granite with the quartz-porphyry may be traced on the surface for a long distance, but the weathering of both rocks has so obscured the boundary that the only clear exposure is in the mine. Here the porphyry becomes felsitic along the junction, and carries for some distance back unaltered inclusions of the older rock. The contact is sharp and well defined, but as the two rocks are separated from each other by a seam of gouge the question of its being a fault-contact is at once raised.

A direct contact between the granite and the limestone is said to have been exposed in the workings of the old Grand Prize mine a short distance to the east of the cupriferous deposits. These workings are now inaccessible, and although the property was visited, but little of a geological nature could be ascertained. The ores are said to have been wholly of lead, copper being absent.

It is unfortunate that the contacts of the granite with the other rocks have not been better exposed.

IV. Descriptions of the Rocks.

1. *Granite.*

The extent of the granite has already been noted, and it is believed to be the fundamental rock of the district, all the evidence pointing to this conclusion. This cannot be stated with

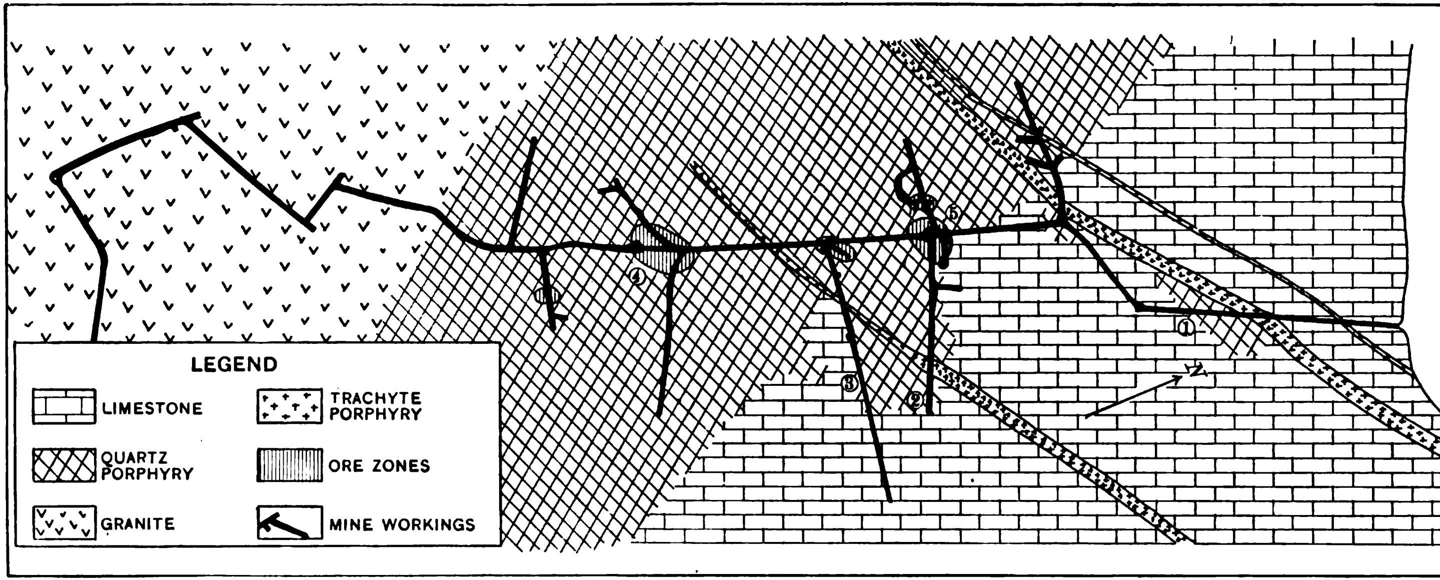

Fig. 4.—Horizontal Geological Section on the Line of the 700 Ft. Tunnel (Albert Tunnel).

certainty, however, as the geological investigations were not carried out over a sufficiently extended area to produce conclusive evidence.

The granite is a coarsely-crystalline rock revealing to the unassisted eye orthoclase and quartz with a little biotite; the dark silicates are present in very subordinate quantity or are lacking. Under the microscope the same minerals appear as those just mentioned. Some plagioclase is also apparent, and there is a rather decided tendency toward a coarse porphyritic texture. Larger feldspars and quartzes stand out in comparison with others smaller and with the dark silicates.

The granite exposures where studied were of very uniform texture and show no evidence of foliation or other effects of dynamic action, such as are frequently met in the older rocks of this class.

As previously stated, the only ores which occur in the granite carry lead. Copper has nowhere been found in it to our knowledge. The granite weathers easily and crumbles to a coarse sand. In the mine the workings in it are always wet, and the rock disintegrates and swells under the action of the water.

2. *Limestone.*

The limestone in typical specimens is a fine grained bluish rock, though in places in the mine it is almost black from included carbonaceous material. During the driving of several of the cross-cuts through this rock sufficient gas was given off to pollute the air in the workings.

The bedding-planes are not well defined; their prevailing dip is to the east at varying but usually high angles. Bands of chert several feet in thickness are of prominent occurrence, standing out in high relief on the hillsides.

Two analyses have been prepared by J. F. Kemp, from specimens taken near the mouth of the Albert Tunnel. No. 86 was 50 ft. in and was a blue unmetamorphosed variety. No. 96 was farther in and 45 ft. from the contact with the porphyry. It is a white crystalline marble.

	No. 86	No. 96
SiO_2,	14.77	1.38
Fe_2O_3, Al_2O_3,	3.68	1.01
$CaCO_3$,	72.53	96.01
$MgCO_3$,	8.89	1.36
Total,	99.87	99.76

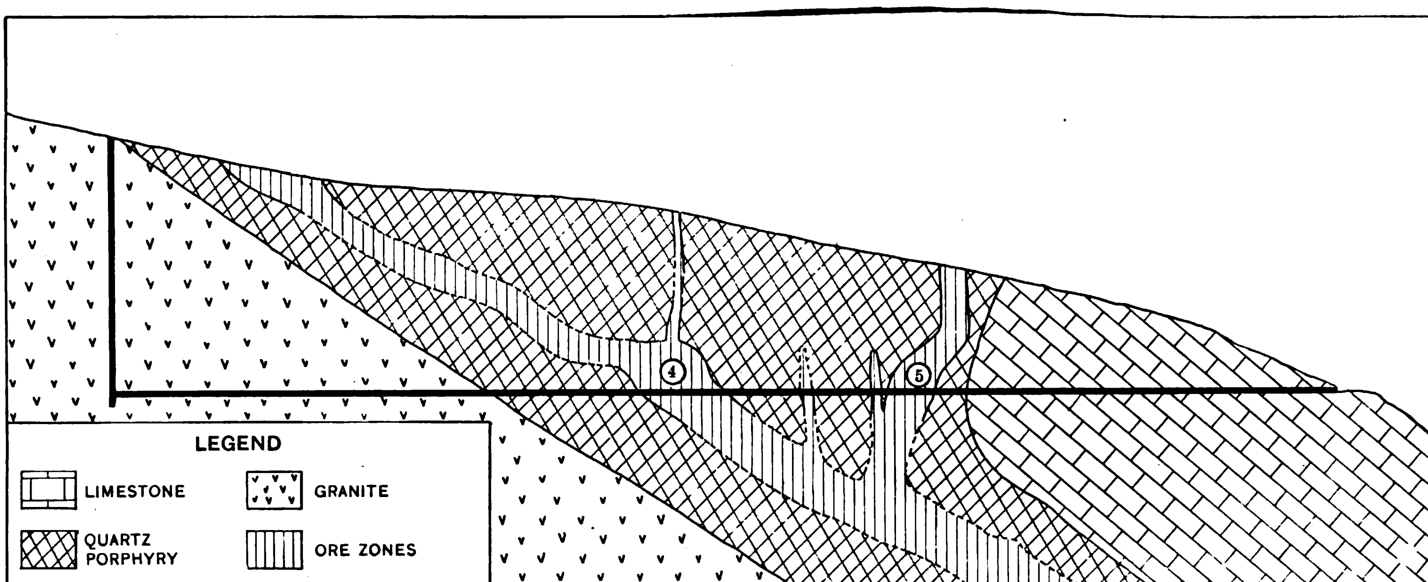

FIG. 5.—VERTICAL GEOLOGICAL SECTION, APPROXIMATELY ON THE LINE OF THE ALBERT TUNNEL.

These analyses show considerable variation, but on account of the peculiar position of the garnetized pipes, or chimneys, within the eruptive, the composition is of less importance than in the usual case of contact metamorphism.

3. *Porphyritic Eruptives.*

The porphyritic eruptives certainly represent two distinct periods of intrusion which yielded two rocks of contrasted appearance to the eye, although composed of much the same minerals. The older rock contains the ore-bodies and varies from a felsite to a granite-porphyry in texture. Masses that are really true granite are also met, but they may be either inclusions torn off from the large granite mass, earlier described, or else textural variations of the porphyry itself. Their occurrence is too irregular and limited to lead us to believe them separate intrusions. Inclusions of limestone appear with even greater frequency.

The second rock is of marked and uniform porphyritic texture, with abundant, large, white phenocrysts, in a gray, felsitic ground-mass. The phenocrysts weather out at times and are in many cases Carlsbad twins of orthoclase. No phenocrysts of quartz have been observed. This second rock forms dikes which penetrate both the older porphyry and the limestone. Its entrance is later than the formation of the garnet, and it simply marks the last eruptive activity in the region.

We shall refer to the earlier rock as quartz-porphyry and to the later one as trachyte-porphyry.

(*a*) *The Quartz-Porphyry.*—We use this general name for the rock because it varies in texture all the way from a finely-crystalline felsite, through rhyolite-porphyry to granite-porphyry. The component minerals are chiefly feldspars and quartz. The quartz often appears as large phenocrysts (see Fig. 6), but again this form may fail. When seen under the microscope the large crystals are often corroded and embayed, sometimes excessively so. The small quartzes in the ground-mass show a marked tendency toward cross-sections that are nearly square and that are evidently cut through small bi-pyramidal crystals. In several specimens from the Albert tunnel, near the granite, excellent micropegmatitic intergrowths with feldspar are met. (See Fig. 8.)

The feldspars are prevailingly acidic plagioclases, but ortho-

clase is also quite abundant. We find large phenocrysts up to an inch in cross-section and very abundantly set in the rather inconspicuous ground-mass, and also small crystals of rectangular or irregular habit forming the ground-mass itself. (See Fig. 7.) The feldspars are in no way remarkable or exceptional and, except for the prevalence of the acid plagioclases, are what we often observe in granite-porphyries.

An analysis of a variety with a moderate abundance of feldspar, set in a finely felsitic ground-mass, is as follows. It was very kindly made for us by Mr. T. T. Read, now of the Department of Metallurgy, Colorado College: SiO_2, 68.43; Al_2O_3, 16.08; FeO, Fe_2O_3, 1.59; MnO, 0.26; CaO, 2.93; MgO, 1.15; Na_2O, 5.36; K_2O, 4.19; Moisture, 0.11; H_2O, 0.61; total, 100.71 per cent.

The analysis in one small particular is incomplete for recasting into the percentages of the component minerals, in that the FeO is not separately determined from the Fe_2O_3, but the amount is so small that no appreciable error is involved if we consider it all Fe_2O_3, and calculate it as biotite, of the formula K_2O, 4MgO, $2Fe_2O_3$, H_2O, $6SiO_2$. There will then remain a few residues of CaO, MgO, and MnO, to be relegated to hornblende or augite, both of which have been often noted in other specimens of the quartz-porphyry. In any event the margin of error is very small. When recast under these conditions the results are as follows: Quartz, 15.40; orthoclase, 22.24; albite, 45.06; anorthite, 8.90; biotite, 4.75; CaO, SiO_2, 2.32; MgO, SiO_2, 0.80; MnO, SiO_2, 0.30, H_2O, 0.40; total, 100.17 per cent.

The rock is thus one in which the light-colored minerals greatly predominate.

In addition to the type of rock which was the subject of the analyses, and which is illustrated by the photomicrograph, Fig. 6, we have others which are coarser and which have a larger percentage of the dark silicates. The increasing coarseness of grain is shown in Fig. 7. The dark silicates are richer in hornblende and augite while biotite tends to diminish. The variations are changes in amount rather than in kinds of minerals.

The supposed inclusions of granite are more basic than the quartz-porphyry and are rather finely granitoid in texture.

They present the same minerals with the additional occurrence in one slide of a crystal of allanite.

The quartz-porphyry weathers rather easily along the crushed zones, rendering the keeping open of the stopes a difficult problem. The granitic facies of this rock appear to be more resistant to weathering than the porphyritic varieties.

In some of the hand-specimens when carefully studied small dikes may be observed, an inch or less in width, cutting other phases of the porphyry and seeming to be other and later intrusions. They are all so small and limited in size and extent and are so exactly the mineralogical composition of the normal porphyry that it is difficult to believe them other than portions which have forced their way while still fluid into crevices in the otherwise already solidified mass. Prof. W. S. Crosby years ago described similar phenomena in the dikes along the Atlantic Coast as "extravasated dikes." At White Knob they are very minor occurrences.

(b) *The Trachyte-Porphyry.*—The trachyte-porphyry occurs in dikes whose widths vary from a very few inches up to 50 ft., cutting through the limestone and the quartz-porphyry.

The texture is coarsely porphyritic, Carlsbad twins are abundant and quartz is visible in but very small quantity, in a felsitic ground-mass which becomes dark on weathering. This rock presents a striking appearance in the mine, the large Carlsbad twins contrasting strongly with the darker ground-mass. The distribution of the phenocrysts, due to flowage, is everywhere in evidence, especially along the edges of the dikes, where the crystals of orthoclase have been drawn out into fine lines.

On exposure to the air the trachyte-porphyry usually softens and swells. No copper or pyritic material has been noted in any of the dikes.

The microscope chiefly seems to corroborate the observations made with the eye alone. A little quartz is visible in the slides and plagioclase appears in greater amount than would be suggested by the Carlsbad twins among the phenocrysts. The relations are similar to those shown in the recasting of the analysis of the quartz-porphyry. The dark silicate is chiefly altered to chlorite, but it appears to have been biotite. No analysis has been prepared of this rock.

FIG. 6.—FINE-GRAINED QUARTZ-PORPHYRY, SHOWING AN EMBAYED QUARTZ BELOW; A PLAGIOCLASE CRYSTAL AT THE RIGHT ABOVE; AND SEVERAL PRISMS OF HORNBLENDE. CROSSED NICOLS; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

FIG. 7.—COARSE-GRAINED QUARTZ-PORPHYRY, WITH A ZONAL PLAGIOCLASE PHENOCRYST. CROSSED NICOLS; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

FIG. 8.—MICROPEGMATITIC PHASE OF QUARTZ-PORPHYRY. CROSSED NICOLS; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

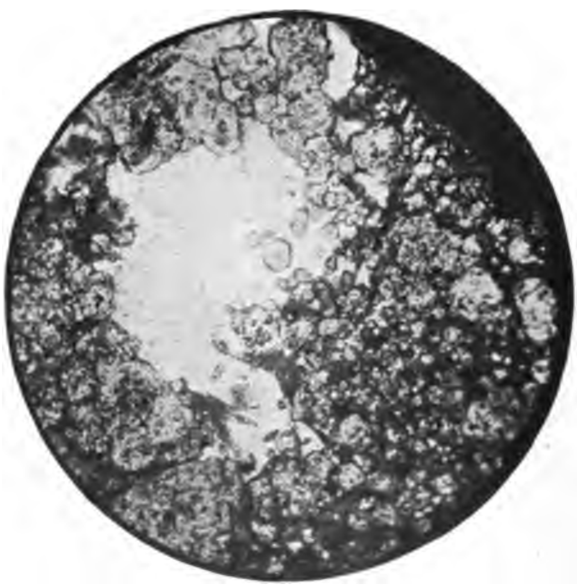

FIG. 9.—GARNETS. THE COLORLESS AREA IS QUARTZ. THE GARNETS BEGIN AS WELL-BOUNDED CRYSTALS, BUT BY MUTUAL INTERFERENCE BECOME IRREGULAR. ORDINARY LIGHT. ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

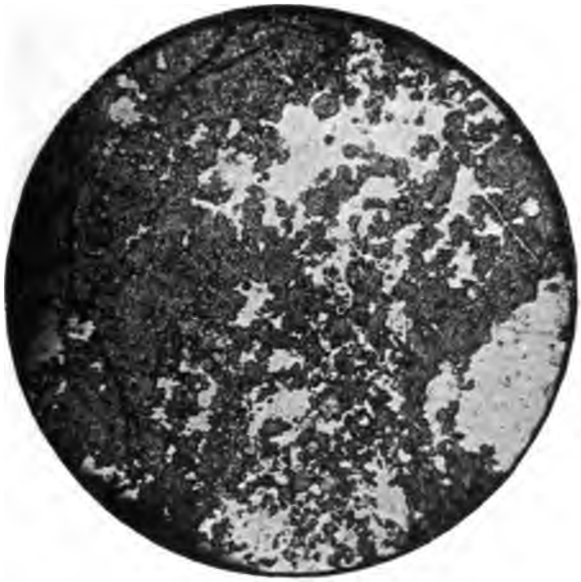

FIG. 10.—GARNETS AND DIOPSIDE TOGETHER IN COLORLESS QUARTZ. ORDINARY LIGHT; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

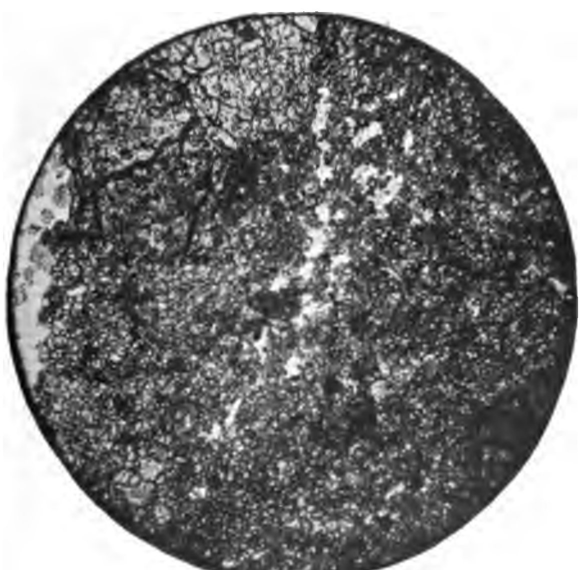

FIG. 11.—DIOPSIDE IN QUARTZ. ORDINARY LIGHT; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

FIG. 12.—THE COARSER GRANULES ON THE RIGHT AND BELOW ARE GARNET; THE FINER ONES, DIOPSIDE. THE COLORLESS AREAS ARE CALCITE. ORDINARY LIGHT; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

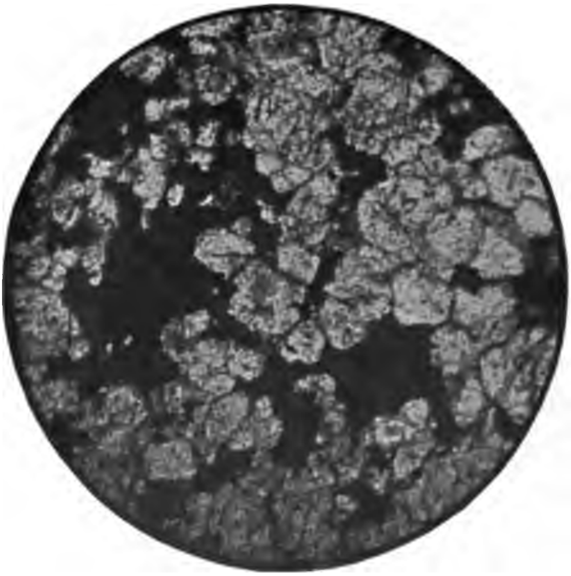

FIG. 13.—THE LIGHTER CRYSTALS ARE GARNET; THE BLACK AREAS ARE CHALCOPYRITE AND MAGNETITE. THE FIGURE ILLUSTRATES THE INTIMATE INTERGROWTH OF THE THREE MINERALS. ORDINARY LIGHT; ACTUAL FIELD, 2.5 MM., OR 0.1 IN.

V. Contact Phenomena.

1. *Comparative Immunity of the Limestone from the Effects of Contact-Metamorphism.*

The comparative immunity from the effects of contact-metamorphism enjoyed by the limestone is remarkable. Along its boundaries with the cupriferous eruptive a few feet at most have been changed to a crystalline white marble, but instances have been noted where typical unchanged limestone carrying bituminous matter occurs within a few inches of such contacts.

It may be stated generally that alteration of the limestone has proceeded to a greater degree along those contacts with the quartz-porphyry where the eruptive carries copper values than where it is unmineralized.

The effect of the intrusive trachyte upon the limestone has been even slighter than that of the quartz-porphyry. Many instances have been noted where the limestone can be traced to a contact with this rock absolutely without visible change.

2. *The Contact Phenomena in the Quartz-Porphyry.*

As is the usual experience, the simplest contact-effect is the change of the blue limestone to white marble. The next effect is the production of tremolite. In one of our specimens this forms a vein about 2 in. thick of fibrous or acicular crystals in apparently unchanged blue limestone. The acicular crystals radiate like spherulites from a center and are individually as much as an inch in length. The tremolite was undoubtedly formed as a replacement-vein by the circulation of heated siliceous waters or vapors along a small original crevice in the limestone. Its production left the walls of blue limestone practically unchanged. Similar phenomena are reported by Lindgren from Morenci, Arizona.[1]

Along the contact of the quartz-porphyry and the limestone, garnet rock is not of prominent development. Its almost exclusive occurrence is within the eruptive mass itself, with which it makes a very complex intermixture. The mineralogy and petrography of these lime-silicate rocks will first be set forth, after which the subject of their development will be taken up.

[1] *Professional Paper* No. 43, *U. S. Geological Survey*, pp. 160, 161.

The chief mineral is garnet. This varies from a light amber-colored or pale yellow translucent variety, whose composition is shown in analysis No. 1 below, through various shades of pale green and brown to deep reddish brown and almost black. Crystals of all sizes, up to an inch in diameter, have been developed in cavities and are often coated with calcite or chalcopyrite. The forms are the usual combination of the rhombic dodecahedron and the tetragonal trisoctahedron, sometimes one, sometimes the other form predominating. The very beginnings of small garnets are shown in Figs. 8, 9, and 10, and the growth of larger ones is illustrated in Fig. 13. In each case they develop well-bounded crystals until in growth they interfere with one another.

TABLE I.

	1	2	3	4	5
SiO_2, ...	37.07	37.79	37.15	42.63	36.26
Al_2O_3, ...	17.42	11.97	6.98	1.53	0.78
Fe_2O_3, ...	10.81	15.77	19.40	31.41	32.43
FeO, ...	0.68	1.31	......	0.30	0.32
MnO, ...	......	0.31	......	0.43	0.27
CaO, ...	32.77	32.57	32.44	23.37	29.67
$CaCO_3$, ...	......	......	4.20	None.	None.
MgO, ...	0.51	0.37	......	......	......
H_2O, ...	0.14	0.09	......	......	0.13
H_2O+	0.39	......	......	......	0.44
Soluble Fe_2O_3, Al_2O_3, etc.,	......	......	0.43	......	......
Total, ...	99.79	100.18	100.60	99.67	100.30

1. Light amber-colored garnet, White Knob, Idaho, by Cyril Knight.
2. Massive garnet, White Knob, Idaho, by T. T. Read.
3. Garnet, San José, Mexico, J. P. Kemp, *Trans.*, xxxvi., 192 (1906).
4. Garnet, Morenci, Ariz., W. Lindgren, *Professional Paper* No. 43, *U. S. Geological Survey*, 134.
5. Garnet, Morenci, Ariz., W. Lindgren, *Professional Paper* No. 43, *U. S. Geological Survey*, 134.

Much more abundant than the crystalline or distinctly granular garnet rock, is a dense, often aphanitic variety with a peculiar greasy luster. Its garnet character might not be suspected at first sight, but under the microscope one sees that it consists of this mineral with almost nothing else. An analysis of a typical specimen is given under No. 2. Three garnets from the contact-zones of other localities are added under Nos. 3, 4, and 5.

All of the analyses in Table II. have been recast in order to

discover and emphasize the variety of garnet which occurs in the zones. The prevailing impression is that grossularite, the lime-alumina variety, is the principal and characteristic one. Increasing experience shows, however, that this is a mistake and that andradite, the lime-iron molecule, is much more wide-spread than has been generally believed. So far as the determinations have gone, we cannot but be impressed with the small percentages of FeO, MnO, and MgO, all of which oxides enter in only a subordinate way.

TABLE II.

	1	2	3	4	5
Grossularite.					
$3CaO, Al_2O_3, SiO_2$,	69.26	47.82	31.00	6.02	2.96
Andradite.					
$3CaO, Fe_2O_3, 3SiO_2$,	21.13	44.16	61.10	67.62	86.30
Almandite.					
$3FeO, Al_2O_3, 3SiO_2$,	1.61	2.99			
Pyrope.					
$3MgO, Al_2O_3, 3SiO_2$,	1.44	1.31			
Spessartite.					
$3MgO, Al_2O_3, 3SiO_2$,	......	0.68	......	0.91	0.79
Hematite,	4.25	1.90	......	7.30	4.80
Magnetite,	......	......	......	1.00	1.00
Kaolin,	2.61	......	1.04		
Wollastonite.					
CaO, SiO_2.					
Quartz,	......	1.32	2.58	17.46	4.26
Calcite,	......	......	4.20		
Water,	......	0.09			
Total,	100.30	100.27	99.92	100.31	100.11
Excess of SiO_2	0.54				
	99.76				

In recasting the last two analyses, in Table II., which are taken from Mr. Lindgren's paper,[2] in the calculated mineralogy varies in some particulars from the one observed and recorded by the author. No magnetite, for example, is mentioned by him, and the quartz is perhaps in excess of what would be inferred from his descriptions. But the great point is not affected—viz., to show the kinds and relative amounts of the several garnet molecules.

Next after garnet, diopside is the most abundant mineral. It appears in finely granular aggregates of brightly polarizing

[2] *Professional Paper No.* 43, *U. S. Geological Survey*, p. 134.

properties. In the hand-specimen the grayish finely-crystalline rock often corresponds perfectly to the old name, lime-silicate-hornstone, and might be taken for a felsite, but a little experience with the microscope corrects the impression that it is an eruptive. The very beginnings of diopside in finely-granular masses are shown in Fig. 11. Its simultaneous growth with garnet is illustrated in Figs. 10 and 12. The following analysis by T. T. Read, to whom grateful acknowledgments are due, illustrates the chemical composition. It has been recast with the results which follow:

Diopside rock.	Per Cent.	Quantity of Minerals.	Per Cent.	
SiO_2,	45.85	Pyroxene:		
Al_2O_3,	12.21	CaO, SiO_2,	59.15	Diopside.
Fe_2O_3,	2.15	MgO, SiO_2,	8.60	Diopside.
FeO,	2.49	FeO, SiO,	4.59	Diopside.
CaO,	28.54	MgO, Fe_2O_3, SiO_2,	2.91	Augite.
MgO,	8.70	MgO, Al_2O_3, SiO_2,	24.21	Augite.
Total,	99.94	Quartz,	0.12	
		Total,	99.58	

The analyses indicate 72.34 per cent. of diopside, strictly speaking, and 27.12 per cent. of the augite molecule. The pyroxene is therefore not pure diopside, but only predominantly composed of this mineral.

Wollastonite has been detected in several specimens, but it is not an abundant mineral in the zones. Its molecule, CaO, SiO_2, forms nearly 60 per cent. of the specimen of diopside whose analysis is given above, but there is enough of the other molecules to destroy the identity of the wollastonite itself.

Vesuvianite and epidote, both closely related to garnet in composition and characteristic components of garnet zones, have been identified but are rare. The former is 5CaO, MgO, Al_2O_3, AlOH, $5SiO_2$, and the latter 2CaO, Al_2O_3, AlOH, $3SiO_2$. The formulas will make clear that their occurrence in the zones is entirely natural and to be expected, and it is perhaps surprising that they are so rare.

Scapolite, a mineral not especially abundant in the zones associated with copper deposits in the West, has been once detected in the slides. It is a lime-alumina silicate which involves also some sodium and chlorine. It is so complicated that on

account of its rarity it will not be discussed in greater detail. Its composition is also one to make it a very natural member of the contact-zone group.

Fluorite, the calcium fluoride, appears in quite large amounts in the upper and branching portions of the deposits. It is mingled with magnetite, chalcopyrite, the light, amber-colored garnets, and calcite, and is a very natural product of the pneumatolytic processes which produce the contact effects.

Calcite is widely distributed, both among the other components of the zones and as crusts and veinlets more recently formed than they.

Gypsum has also been observed as a mineral of late development, probably produced by the alteration of the sulphides.

Quartz is of wide distribution, although not in large amount. It either forms veinlets through the others or crusts of clear crystals.

Metallic minerals are not numerous or greatly varied. The original ones include magnetite and specular hematite, pyrite, chalcopyrite, bornite, and rarely a little zinc-blende and galena. Among the secondary minerals chrysocolla is much the commonest of those containing copper, although malachite and chalcocite are not unknown. Limonite results from the oxidation of the pyrite and chalcopyrite, and may so richly contaminate the chrysocolla as to yield the brown resinous variety of the latter, the *Kupferpecherz* of the German miners.

The order of formation of the several minerals seems to be the following: Garnet, diopside and probably the related silicates, vesuvianite and epidote, were the first, and where they could grow freely they developed well-bounded crystals. Before their period closed, magnetite, chalcopyrite, pyrite and specularite began, since the latter are found as inclusions in the silicates. (See Fig. 13.) But the sulphides certainly continued longer than the garnet, because they incrust its well-developed crystals. Bornite appears to be a later mineral, since in one or two specimens it forms veins cutting the garnet rock. It has been found mottled with inclusions of chalcopyrite, but whether it has resulted from the enrichment and replacement of earlier existing chalcopyrite or is itself original is difficult to decide.

In the alteration and secondary enrichment by far the com-

monest mineral to form has been chrysocolla, and it does not appear to have moved far from its parental chalcopyrite. As will be more fully brought out later, it seems as if the abundant silica in the minerals of the gangue locked up the copper in the hydrated silicate before appreciable migration had been accomplished. The relatively small amounts of calcite have, however, sufficed also to produce a little malachite. Chalcocite has been noted in but one place in the mine, and then in but small amount.

3. *The Form and Distribution of the Ore-Bodies.*

Both in form and in relations to the country-rock these ore-bodies are different from any which are known to us, and therefore much care has been exercised in preparing Figs. 2, 3, 4 and 5, which are intended to illustrate them and which are based on careful geological observations. The endeavor has been made to indicate what is known and what is inferred. The known boundaries are drawn in full lines, the inferred in dotted.

In Fig. 2 the surface geology is shown and the profile is in some degree indicated by the section, Fig. 5. It is at once apparent that the ore-shoots outcrop altogether in the quartz-porphyry, except for one small one, which is associated with an outlying dike in the limestone at 1 Fig. 3. Ten shoots are shown in the quartz-porphyry, some near the contact with the limestone, others near the granite. In depth the tendency seems to be rather to approach the limestone than otherwise, and this is brought out in Fig. 5.

Each of the ten exposures on Fig. 3 marks a chimney of garnet rock whose course has been shown by the workings to be sinuous when followed downward. The chimneys also tend to come together with descent, but never, so far as known, to do the same with ascent. The northern group marked "5" on the map, Fig. 4, and illustrated more fully on Fig. 5, has been continuously opened by winzes, up-raises and stopes for 500 ft. from the surface to the level of the Albert tunnel, and we note that, as shown on this figure and on Fig. 4, the disposition of the chimneys to coalesce is pronounced. Again, if we take No. 4 of Fig. 4 and Fig. 14, of which the latter represents a

section of the southern shoot, 60 ft. above the former, the coming together within this distance is noticeable.

In the inferential portion of the section, Fig. 5, the hypothetical coalescence of all the shoots into one parent trunk in depth is indicated and is believed to be highly probable.

At the surface the northern group of garnet-shoots appeared as a capping of limonite which carried a small percentage of copper as the red oxide. Druses of bright unaltered specularite occurred in cracks throughout the mass. Masses of limonite occasionally inclose nuclei of unaltered cupriferous pyrite. As we descend, chrysocolla becomes the copper-bearing mineral, and pyritic matter is encountered but a short distance below the surface. From this zone down no changes in the mineralogical combinations of the copper take place. The bulk of the ore is cupriferous pyrite in a gangue of garnetized and altered quartz-porphyry. Through this mass percolating surface-waters have developed channels of oxidized ores, consisting of chrysocolla and, in lesser quantity, malachite as stains through the brecciated eruptive. At or just below the 700-ft. or Albert tunnel-level, a split has taken place in this ore-body, a sheet of pyritic matter branching off from the main chimney and continuing upward away from it with a southerly trend. This ore-body has been opened below the tunnel-level through a winze; the ores are the same as those stoped from the upper levels, and of similar grade, both oxides and sulphides being present in different parts of the chimney.

In the winze on the tunnel-level above mentioned and at a point about 210 ft. above this level, limestone forms the northern limit of this ore-zone. It has been altered to a white marble where exposed in the stopes, but that the alteration has taken place for a few feet only has been shown wherever the limestone has been penetrated by a cross-cut.

The southern ore-chimney (No. 4 on Figs. 4 and 5) is rather larger at the tunnel-level than the northern chimney just described, but immediately above, it splits into two bodies of nearly equal size, which steadily diverge as they go up. In the eastern branch are found the fumaroles described two paragraphs below. The western branch splits into several smaller branches a short distance above its junction with the eastern chimney; the conditions obtaining 60 ft. above the tunnel-level

are shown on the map, Fig. 14; within a vertical height of 60 ft. the one large chimney at the tunnel-level has split up into five parts.

The ores and their distribution in the northern and southern chimneys are essentially similar, with the exception that those of the southern chimney, although at a greater depth below the surface where opened, are the more completely oxidized.

The smaller ore-shoots shown on Fig. 3, and the surface exposures are, in so far as developed, entirely similar to the typi-

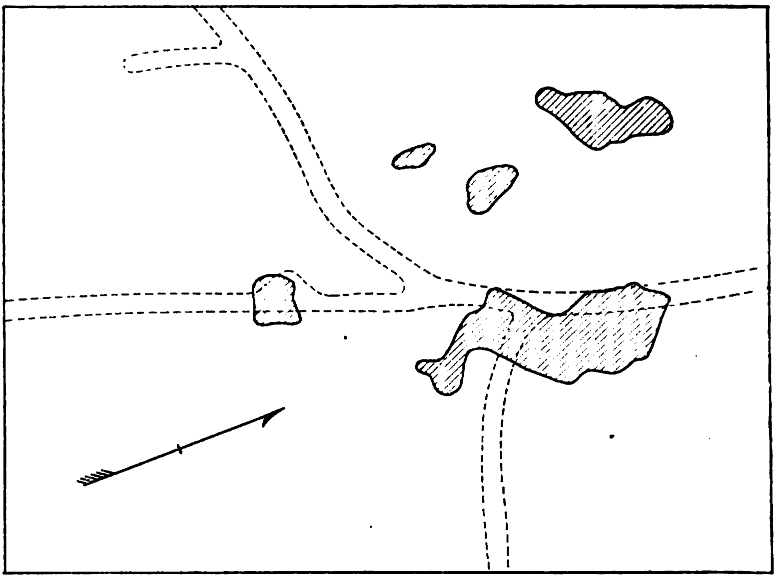

FIG. 14.—HORIZONTAL SECTION THROUGH THE SOUTHERN ORE-BODY, 60 FT. ABOVE THE ALBERT TUNNEL. THE DIVERGENCE OF THE SHOOTS WITH ASCENT IS SHOWN. COMPARE NO. 4 OF FIG. 4. THE DOTTED LINES ARE THE TUNNEL AND DRIFTS.

cal chimneys described, and a detailed account of them would only be a repetition of the foregoing.

On the 9th floor of the east stope on the ore-chimney marked 4 on Fig. 3, there has been exposed a cluster of what may very well be termed "pipes," or "flues." These are surrounded for perhaps a radius of 20 ft. at the point exposed by an intimate mixture of finely-crystallized garnet and specularite, which carries pyrite and chalcopyrite, and their products of oxidation, and fluorite in small but persistent quantity. Through

this mass are vugs lined with crystalline garnet, and in several places angular fragments of unaltered quartz-porphyry cemented in the mass, bearing testimony to the fumarolic processes.

The pipes themselves are lined with incrustations of garnet and specularite. Crystalline purple fluorite is present and chalcopyrite occupies the spaces between the other minerals. Additional minerals of probably later origin are siderite incrusting the other minerals, gypsum, which occurs in a similar manner, and calcite, which has come in latest of all, filling the open spaces between the larger crystals and the cracks through the formation.

These pipes vary in size from those which are now closed, but which exhibit the original structure, to open channels from 8 to 10 in. across.

In the north drift on the second level from the shaft at the point marked 8 on the geological-map, Fig. 3, there is a similar occurrence. The resulting mineralization has not been over as extended an area as in the case already cited, but the two occurrences are essentially similar.

VI. The Method of Deposition.

In tracing the method of formation of these ore-shoots we have therefore to account for their cylindrical character, their sinuous and forking courses, and their limitation to the quartz-porphyry. The most reasonable and natural explanation is that they have been produced by the passage of highly-heated solutions or vapors, or ionized water-gas, through the quartz-porphyry and probably while the latter was still viscous or not entirely solidified. The vapors, for such they would appear to have necessarily been, if the quartz-porphyry were still unsolidified, must have been highly charged with lime and iron. The lime and iron combined with the components of the porphyry to yield the garnet and diopside rock of composition shown by the analyses. We have sufficient data to roughly calculate if this change was probable, or at least to determine what new additions to the quartz-porphyry would be necessary. We must assume that the silica, which is already in excess in the quartz-porphyry, is not increased, but rather is brought down to the grade of the contact rocks by additions of bases. We

also assume that the alkalies of the quartz-porphyry are eliminated, since they are not found in the garnet and diopside rocks. The fundamental analyses upon which the calculations are based are given in Table III., but several minor ingredients are omitted in recasting.

TABLE III.

	1	2	3	4	5	6	7
	Quartz Porphyry.	Crystallized Garnet.	Massive Garnet.	Diopside.	Quantities added to 1 to yield 2.	Quantities added to 1 to yield 3.	Quantities added to 1 to yield 4.
	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
SiO_2, .	68.43	37.07	37.79	45.85			
Al_2O_3, .	16.08	17.42	11.97	12.21	16.08	5.59	2.14
Fe_2O_3, .	1.59	10.81	15.77	2.15	19.74	29.59	5.75
FeO, .	......	0.68	1.31	2.49			
MnO, .	0.26	......	0.31				
CaO, .	2.93	32.77	32.57	28.54	57.57	56.04	39.66
MgO, .	1.15	0.51	0.37	8.70	......	......	11.83
Na_2O, .	5.36						
K_2O, .	4.19						
Moisture,	0.11						
H_2O, .	0.61						

In these determinations the MnO, and MgO of Nos. 2 and 3 were rejected, as they amount to but little. Since FeO was not determined in No. 1 all the FeO respectively of Nos. 2, 3 and 4 was recast as Fe_2O_3, and was added to the Fe_2O_3 of the analyses, and these totals were then used. The small components make very little difference at best. The calculations are based upon continuous proportions to which the silica of the eruptive gives the clue.

Thus for the crystallized garnet No. 2:

$$68.43\ SiO_2 : (16.08 + 16.08)\ Al_2O_3 : (1.59 + 19.77)\ Fe_2O_3\ (2.93 + 57.57)\ CaO.$$

$$\text{as } 37.07\ SiO_2 : 17.42\ Al_2O_3 : 11.56\ Fe_2O_3 : 32.77\ CaO,$$

$$\text{or, as } 37.53\ SiO_2 : 17.64\ Al_2O_3 : 11.70\ Fe_2O_3 : 33.18\ CaO.$$

Should a reader verify these, it must be borne in mind that the summation of the values in the middle member of the continued proportion does not total an even hundred, and allowance must be made for the missing percentages. Thus, as the summation is 98.82, we must raise each by practically 1.2 per cent., giving the third member, which figures were used. It should also be added that in re-casting analyses 3 and 4, so as to obtain Nos.

6 and 7 other but analogous proportions are required. After raising in Nos. 3 and 4, the FeO to Fe_2O_3, the second member of the proportions adds up so nearly 100, that no correction was esteemed necessary.

Solutions which would furnish the required accretions for Nos. 5, 6 and 7 would have their dissolved solids in the following proportions:

	5a	6a	7a
Al_2O_3	17.2	6.13	3.61
Fe_2O_3	21.2	32.44	9.68
CaO	61.6	61.43	66.79
MgO	....	....	19.92
	100.00	100.00	100.00

The alumina is the only component which presents any particular difficulties, for the others are very common ingredients of mineral springs. Thus, Berzelius[3] found the following results for the *sprudelstein* of the Carlsbad springs, whose waters are now considered by some observers to be magmatic in origin. In a general way the composition is closely akin to the ones required above.

	Per Cent.
$FeCO_3$,	12.13
Fe_2O_3,	19.35
$CaCO_3$,	53.20
Basic iron phosphate,	1.77
Alumina phosphate,	0.60
SiO_2,	3.95
H_2O,	9.00
Total,	100.00

Beyond this coincidence in compositions it does not seem possible to go in the way of positive evidence. We must therefore build up our conceptions by imagining the emissions of suitable compositions passing upward through the substance of the quartz-porphyry and yielding the chimneys.

The question may be raised, whether the mineralization may not have been produced along fissures in the already solidified porphyry and by heated waters. Fissures have been sought with great care in the mine and many joints have been plotted. But no coincidence can be traced between them and the garnet chimneys; much less can any intersection of fissures be shown

[3] Quoted in Roth's *Allgemeine und Chemische Geologie*, vol. i., p. 579 (1879).

where the chimneys exist. The conclusion has therefore been reached that the uprising gases and vapors passing through a molten or viscous mass have at least established the lines for the development of the garnet, diopside and other minerals. If the necessary ingredients were contributed to a still-molten rock, the chimneys must have later solidified as masses of garnet and diopside when the temperature fell.

The passing of solutions undoubtedly continued after the consolidation of the garnet-zones, since we find fluorite and even quartz filling the interstices in the other minerals.

When the chimneys had been formed, elevated to their present position, and subjected to the meteoric waters within the vadose reigon, the alterations took place which have led to the production of the chrysocolla as the chief result. Once the copper passed into solution in the oxidation of the sulphides, it seems to have combined with silica to give the hydrated silicate and to have remained near its source. Waters now trickle downward in the stopes and winzes at numerous places. They have been drunk freely by the miners with no ill-effects. Samples were carefully gathered in many parts of the mine and tested for copper by Mr. T. T. Read with the most delicate reagents. No discernible amount of copper could be detected. There seems no reason, therefore, to infer the existance of a mass of enriched ores in depth.

To the student of the specimens as well as to one who goes over the map without experience on the ground, the hypothesis may suggest itself that the granite is the intrusive and that the quartz-porphyry is its border facies, chilled into the denser texture by contact with the limestone. Observation on the spot, however, has led to the conclusion that the granite is a separate and distinct rock from the quartz-porphyry, and that it is older.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

An Early Instance of Blowing-In Without "Scaffolding-Down."

BY FRANK FIRMSTONE, EASTON, PA.

(New York Meeting, April, 1907.)

IN the early decades of the past century the method of starting iron blast-furnaces by "scaffolding-down" seems to have been in universal use for coke-furnaces and, at least in this country, for charcoal-furnaces also. It was likewise used at some of the early anthracite-furnaces, as is stated in the important "Reminiscences" printed by the late Samuel Thomas.[1]

It had been generally superseded in Great Britain as early as 1850, by some variations of the plan now used, and was rarely used when Percy wrote.[2]

On the Continent it was still followed in the 60's,[3] and was elaborately described by Valerius in 1852.

I have never read any statement as to when and by whom "scaffolding" was first dispensed with, but the following extracts from journals of my father seem to fix an authentic date for an instance in this country:

"[Pittsburg] July 12, 1838.—Went with Major Wade to his foundry, etc., and he gave me a letter to D. Tyler, Esq., Farrandsville, Agent Boston Coke & Iron Co."

"[Lockhaven, Pa.] July 18, 1838.—Heard there was a flat-boat going to take some gentlemen up to Farrandsville. Got on boat and to Farrandsville, 5 or 6 miles, in 1 hr. 30 min. Dined, and then delivered my letter to Mr. Tyler, who showed me much attention, and everything belonging to the furnace, and had the water turned on the wheel that I might see the blowing-cylinders at work. There are two cylinders, 6-ft. stroke, 56 in. in diameter, but they find that one makes more than enough blast for the furnace. The furnace has 16-ft. boshes, 7-ft. tunnel-head, and is 47 ft. high, 3 tuyeres, and 3 heating-ovens [hot blast-ovens]. A most beautiful stack, the finest I ever saw. They have tried three times to start the furnace . . . and have failed each time; longest time of blowing, a week. They have now a person by the name of Perry from Staffordshire, who is going to start her."

[1] *Trans.*, xxix., 914, 915 (1899).

[2] *Iron and Steel*, p. 491 (1864).

[3] De Vathuer, *Etudes sur les Hautes Fourneaux*, p. 143.

On Oct. 28, 1838, being at Karthaus Furnace, Clearfield county, which then was owned by Burd Patterson, Henry C. Carey and others, he writes:

"Professor Johnson, Philadelphia [Walter R. Johnson], arrived with a letter from Mr. Carey, in which he says: 'Professor Johnson visits Karthaus with a view to see what we have done and what we may do, and request you will give him every information, etc.' . . . Mr. Johnson says they blew in at Farrandsville and made 10 or 15 tons good grey-iron and blew out for want of water; that they filled her above the boshes with charcoal, then put on coke for a few feet and burdened her, and then blew off without scaffolding. He says their hearth is of fire-brick in segments, thinks about 18 in. by 12 in., and that the walls are 4 ft. thick."

This seems to establish beyond doubt that Perry, who afterwards blew in the anthracite-furnace at Pottsville,[4] used the present method of dispensing with "scaffolding" in the late summer or early fall of 1838. It is worth noticing that at that time the hearths were almost always built of sandstone, both here and in Great Britain.[5] One reason for the use of the tedious method by scaffolding was that the hearthstones were thereby more gradually heated up than by blowing at once, as we now do, and consequently were less likely to suffer by spalling. This reason failed, of course, when the hearth was built of fire-brick, as was the case at Farrandsville.

Whether Perry was the first to dispense with scaffolding, and whether this was the first occasion when the method was used, does not, of course, appear, but certainly it was practically unknown at that date.

I am inclined to think that Farrandsville was the first furnace in this country to make iron using both coke and hot blast.[6]

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[4] *Trans.*, iii., 153 (1874-5).

[5] Percy, *Iron and Steel*, p. 477 (1864).

[6] Swank, *Iron in All Ages*, 2d ed., p. 369 (1892).

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Extraordinary Faulting at the Berlin Mine, Nevada.

BY ELLSWORTH DAGGETT, SALT LAKE CITY, UTAH.

(New York Meeting, April, 1907.)

THE Berlin gold quartz mine is situated in Nye county, Nevada, on the west flank of the Shoshone range, about 40 miles south and 30 miles west from the town of Austin, the county-seat of Lander county. The distance from Austin is about 60 miles by stage-road.

The outcrop of the vein, at the top of the incline-shaft, is situated just at the base of the mountain proper, almost exactly at the intersection of the mountain-side with the gravelly bench that slopes for about three-quarters of a mile to the flatter sage-brush plain, or desert valley, below.

The vein itself consists almost entirely of quartz, with perhaps 2 per cent. of sulphide of iron, copper, lead, zinc and antimony, and perhaps a trace of some of the compounds of tellurium with gold and silver, although none of the latter have been as yet positively identified.

The relative proportion, by weight, of silver and gold in the ores, varies in different parts of the vein, from 12 silver for 1 of gold, to 7 silver for 1 of gold.

The quartz vein-filling is usually frozen fast to the walls, and is very hard and compact, seldom showing the friable, fissured, or shelly structure often to be found in quartz veins.

Comparatively little evidence of relative motion of one wall of the vein upon the other is to be found—a fact indicating that during the formation of the vein, and prior to the extensive movements herein described, little disturbance had taken place. No evidence whatever of metasomatic origin has been observed. On the other hand, occasional occurrences of comby structure, in which the axes of the quartz crystals are at right angles to the plane of the vein, rather indicate deposition from solution in a pre-existing fissure.

Spurs, or branches, and small parallel veins, while not en-

tirely absent, are not thus far very numerous, and not extensive enough to possess any marked practical importance.

The thickness of the Berlin vein varies from a few inches to 8 ft., but, over far the greater portion of the explored area, is tolerably uniform at from 2 to 3 ft., measured normal to its plane. The average thickness of quartz thus far stoped, as determined by all available measurements, is a little less than 2.5 feet.

The course of the vein is NE. and SW., and its average dip about 45° to the SE.

The Berlin vein, prior to the extensive faulting described in this paper, was tolerably uniform in size, course and dip, and perhaps, on the whole, rather more regular than the average of gold-quartz veins.

It appears to have been a fissure filled with quartz, and may be said to have originally been in shape, structure and origin, a typical "old-fashioned" fissure-vein of the books.

Throughout the entire field covered by the underground works of the Berlin mine, the rock is andesite, which is, however, in places, locally so altered by compression or movement as to change considerably its appearance and structure. Some very limited chemical changes may also have occurred in places, by reason of which the above-given classification might, to a small degree, fall short in completeness.

The underground workings, including the stopes, of the Berlin mine, as existing July 1, 1906, are shown in plan in Fig. 1, which is a reduced copy of the working-plan of the mine, from which, for the sake of plainness, most of the survey-lines, station numbers and heights above the datum-plane have been omitted.

The stopes, shown by the shaded areas, have in general the form of a more or less irregular parallelogram, suggesting at a glance the extensive faulting in two directions, to which the vein has apparently been subjected.

The ore-bodies, properly enough called segments, are usually terminated on all sides by fault-planes. Those on the east and west sides, though just as truly fault-planes, have been locally called breaks, which term will be retained in this paper for the sake of identification.

The lines bounding the segments, as projected on the plane

FIG. 1.—PLAN OF UNDERGROUND WORKINGS OF THE BERLIN MINE.

FIG. 1A.—STRATIGRAPHY OF THE BERLIN MINE.

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These bodies, properly enough called segments, are usually bounded on all sides by fault-planes. Those on the east and west sides, though just as truly fault-planes, have been locally called breaks, which term will be retained in this paper for the sake of identification.

The lines bounding the segments, as projected on the plane

FIG. 1A.—STRATIGRAPHY OF THE BERLIN MINE.

of Fig. 1, are mainly lines of intersection of the faults and breaks with the vein, and their projections do not at all represent the true course of either the fault-planes, the break-planes, or the vein.

In Fig. 1, the heights shown in brackets refer to a datum-plane 500 ft. below the top of the Berlin incline-shaft. The height of No. 8 level at the shaft is 137 ft. Figures not inclosed in brackets represent survey stations. The stopes, where limited by full lines, are not cut by faulting fissures, but end on account of poor or thin ore, or some similar reason.

Fig. 2 is a vertical section along line *A B* of Fig. 1 through Station 10, on the surface at the outcrop of the vein, and Station 0, on the No. 6 level, as shown in Fig. 1. In this section those portions of the Berlin vein actually stoped out are shown as a solid black line, while the probable position of the unstoped vein is indicated by two parallel lines. The marginal figures in Fig. 2 show the heights above the datum-plane.

The plane of this section was carefully chosen so as to avoid the faults, and Fig. 2, considered by itself, shows only the disturbances apparently due to the breaks.

The light dotted line passing out through the surface-line may be considered as an elevation, showing the minimum heights which the segments could have occupied prior to the faulting herein considered. The actual height from which the present segments have dropped to their present position may have been several times as great, as shown by the dotted lines.

Nor is it yet certain whether the movement was due to the subsidence of the northwest or to the elevation of the southeast portion.

Among many sections made in studying the Berlin underground work, there is one nearly parallel to section *A–B*, but further north, which shows it possible to drive a flat incline-shaft, straight in line and grade, that would cut the vein no less than eight times.

Fig. 3 is a horizontal section, showing the intersection of the Berlin vein and of the break- and fault-fissures with the average plane of the No. 4 level, the average height of which is about 165 ft. below the top of the incline-shaft, or 335 ft. above the datum-plane. The true course of the vein—viz., NE. and SW.; of the breaks, nearly always N. and S.; and of the faults, about

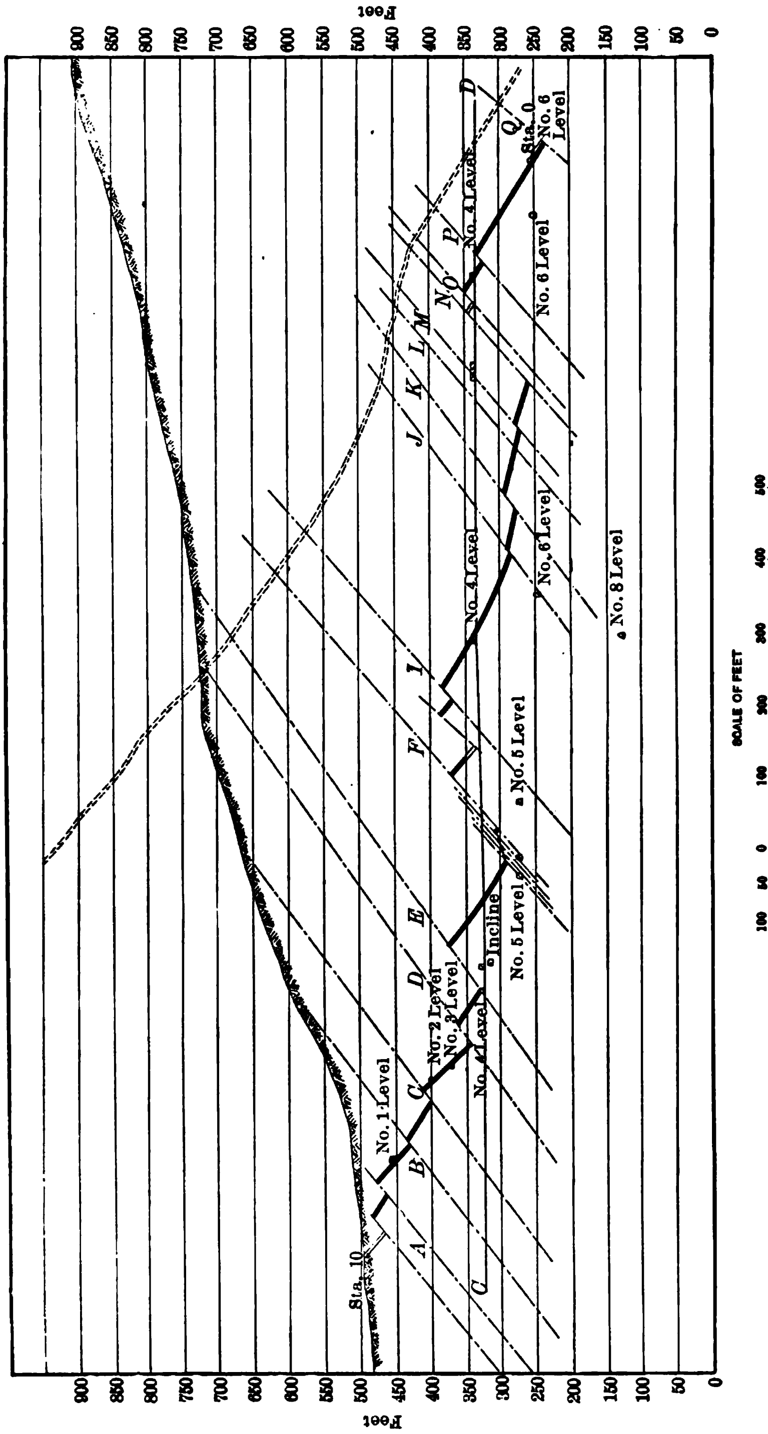

Fig. 2.—Vertical Section Along Line *A B* of Fig. 1.

N. 60° W., is therefore correctly shown in Fig. 3, which, moreover, represents that portion of the fissure system which may be regarded as best known from the present developments.

If we imagine that, in the field covered by Fig. 3, the accidents of erosion had left the surface about at the plane of the No. 4 level, then the heavy black lines would represent the actual surveyed outcrop of a single vein that, before the faulting here described, was probably as regular, as uniform in strike and dip, as nearly in a true plane, and generally as free from eccentricities as the average quartz vein.

So far as my observation goes, this situation is without parallel in quartz mining.

It was at first supposed that the N. and S. fissures or breaks, dipping about 45° W., had first been formed and had faulted the pre-existing vein, and that subsequently a pair of fissures had occurred, each with one or more branches, having a general course about N. 67° W. and a dip of 63° N. 22° E., cutting and faulting both the vein and the breaks. But as developments progressed, and additional intersections of the breaks and faults were found, or indicated, it was observed that in several instances the faults were cut and faulted by the breaks.

In the case of the so-called north fault, shown in Fig. 1, the segments of the Berlin vein, from its outcrop for a distance easterly of about 1,300 ft., have been cut off. It was for a time believed that the south branch of this fissure was a continuous fissure, cut by the No. 4 level at its east end, near survey station 450, and in the north branch of the No. 4 level, near station 459, and again near station 454. But a consideration of the position of the surveyed and known lines of intersection of the fault with the vein forming the north boundaries of the stopes, shows that these intersecting lines were very far from being in the same plane, and that a single fissure, to have contained them all, would have had to be extremely—in fact, impossibly—crooked and irregular.

The conclusion was therefore forced that some of the larger breaks had faulted also the north fault, as well as the vein, and that, instead of one continuous fissure, with a course N. 67° W., there were several fissures with an average course of about N. 60° W., and a dip N. 30° E., of about 63° from the horizontal.

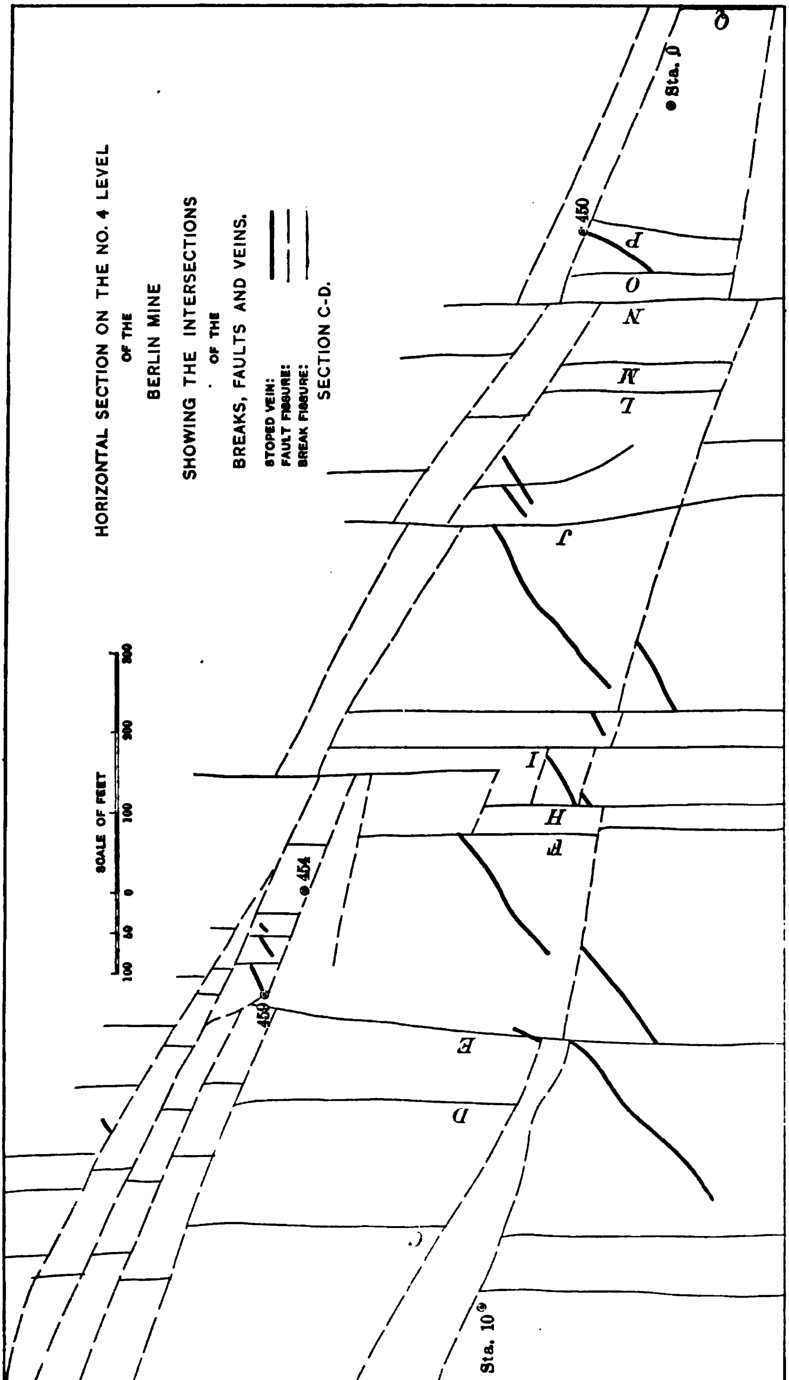

Fig. 3.—Horizontal Section on No. 4 Level.

In practical mining, the main object is, of course, to find and extract the ore as cheaply as possible. It is not often that exposures interesting stratigraphically are incidentally made, or that special work for such a purpose is warranted. In the present case, while in many, perhaps in a majority of instances, the faults do cut and fault the breaks, there is no such uniformity as would enable us to establish the relative age of the two fissure systems. In fact, there are enough instances actually exposed, or undoubtedly indicated, of the breaks cutting and faulting the faults, to make it tolerably certain that the fissures of both systems originated at the same time, and in all probability from a single force.

If we assume that the planes of the break-fissures were in fact parallel to each other, and that the same was true of the fault-planes; that every fissure of each system has been cut and faulted by at least one fissure of the other system, and that the material fissured was rigid, incompressible and inelastic, it would appear that the line of any movement produced by gravity, or by an uplift from any cause, would necessarily be in both planes, and therefore in the line of the intersection of the two planes.

Now, in fact, the planes of neither the breaks nor the faults are exactly parallel. It is not known that every plane of each system has been cut or faulted by one or more planes of the other system. Moreover, andesite is far from rigid, being compressible, and capable of great distortion. Just so far, however, as the conditions existing in the Berlin field approach the hypothetical conditions outlined above, might we expect the direction of the movement to conform more or less closely to the direction of the intersection of the average fault- and break-planes.

Fig. 4 represents a very interesting occurrence, having a significant bearing on this point, which was recently uncovered by the accidental scaling-off of some slabs of clay and gouge in the northwest corner of the second large stope from the east end of the mine. The ore was stoped up to break *J*, but, in the north corner, not quite to the fault-plane—perhaps to within 4 or 5 ft. of it. At point *C*, 12 or 13 ft. along the break southwesterly from the little corner of remaining quartz, there was plainly exposed in the hanging-wall of the break

the edge of a strong, faulting fissure, striking about N. 60° W., and dipping 60° northerly. In this fissure, with some coarser material, was a layer of about 1 ft. of stiff blue clay, evidently the product of attrition. This layer of clay, without any parting whatever, and about uniform in thickness, was continuous around the sharp angle into the break, and up in the break to the quartz remnant, precisely as a layer of lubricant might be found in the V-groove of a planer. It no doubt continues up to the fault-plane on the north, and there turns

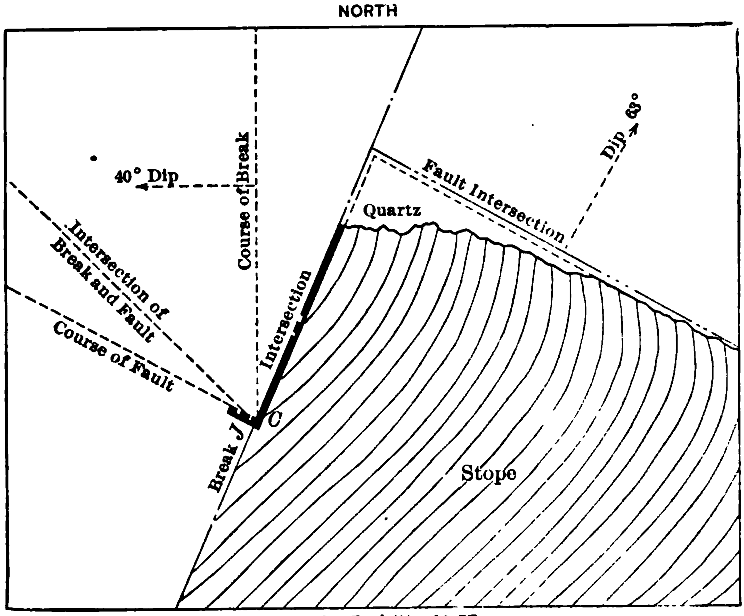

FIG. 4.—INTERSECTION OF FAULT AND BREAK, BERLIN MINE.

down into it. Just southeast of point *C*, a careful examination of the roof and the floor of the stope showed that no sign of fissure existed in the foot-wall of the break. The fault-fissure at *C* is nearly enough in the plane of the fault, which cuts off on the north the next westerly stope, practically to identify it. On the hanging-wall of the break, within a few inches of the sharp intersection of the fault and break, are lines of motion parallel to the fault-plane.

The above conditions indicate that the movement of the north country was one movement, upon both planes at the same

time, and therefore in the direction of the line of intersection of the two planes.

In Fig. 1A are shown the intersections, known and assumed, of the faults and breaks with the vein and with each other, and the entire hanging-country above these intersections is supposed to have been removed.

Figs. 1 and 1A were made about the middle of 1906, and represent the works and known or assumed intersections as of that date. One exception to this latter statement is, that the raise from the No. 8 level encountering ore at point *C* was begun and completed subsequent to the introduction of the lines of intersection.

Intersections of faults and breaks, where not surveyed and known, were then supposed to have the direction N. 45° W.; and the average angle of the intersections of the vein with the breaks was taken as N. 20° E.

Some careful estimates, made since the preparation of Figs. 1 and 1A, and involving all of the principal vein and fault intersections, including both north and south faults, shows these intersections to have an average direction of N. 81° W.

A revised consideration of the breaks shows that the more important breaks have an average dip of 40° W. with a strike, as near as may be, N. and S.

Taking the average course of the vein as N. 45° E., and its average dip at 45° SE., we may, with the average surveyed and known intersections given above, and the known dip of the faults—viz., 63° from the horizontal—determine the average strike of the faults. This has been thus found to be N. 59° W.

The intersection of these planes of the average fault and break, as given above, strikes N. 43° W., instead of 45° as shown in Fig. 1, and dips in that direction 29.5° from the horizontal. The planes of the average fault and break, as given above, make angles with each other of 92° and 88°, the upper angle being 92°. The line bisecting the obtuse angle between these planes runs S. 12.5° E., and dips in that direction 57° from the horizontal. If these calculations be correct, this is the theoretical direction of the pressure or force which produced the two systems of fissures, here called breaks and faults. The existence, before erosion, of a rock-mass, known to be several hundred, possibly several thousand, feet in thickness would,

through the weight of such a mass, supplemented by some lateral pressure, easily account for the fissuring; and gravity alone might be sufficient to explain the movement.

The miner, however, is more interested in the direction and extent of the movement, than in the question, just how it was produced.

In prospecting for the continuation of the Berlin vein, north of the north fault, the problem is complicated by the fact that the break-fissures found in either wall of any of the faults, do not necessarily correspond in their relation to each other with those in the other wall.

The same is also true of the faults. Thus, in the slab of andesite between the breaks *F* and *I* (see Fig. 2) are two known faults, and, in all probability, a third fault. At least two of these, if continuous, should be shown in the large open stopes on either side, but they are not to be found there.

It is also true that the north fault, is probably nowhere in this field a single fault, but that the total movement has been upon two or more nearly parallel fissures, with a slab, or several slabs, of rock, and a segment, or several segments, of vein between them. Moreover, the vein, as a rule, though not always, is uniform in direction and size; hence the identification of the opposite ends of a fault crossing any particular portion is not generally to be expected.

Three occurrences of the Berlin vein, beyond the most northerly known branch of the north faulting-fissures, are known.

At a point 800 ft. N. and 900 ft. W. of the top of the incline, but not shown in the drawings, is a segment of the vein, developed by a short tunnel and a shallow incline. This segment is cut off by an abnormal fault, striking N. 48° E., and dipping about 80° southeasterly, developed by the innermost 100 ft. of the lower tunnel, which is driven upon it. The movement here has been in the opposite direction from other faulting movements shown, and the vein from which the segment at the surface has been cut off has not been found, but is still below the bottom of the lower tunnel.

There is also at the same place an abnormal break known to cut the vein, with a northwesterly course, and a dip of about 45° NE. This may be the southern edge of a series of reverse faults, with a reverse displacement of the vein.

Some work on the No. 8 level, east of point *C*, done since the preparation of Fig. 1, also indicates one or more faults with reverse displacement; but these are as yet not well enough defined to be described here.

On No. 4 level, at the point marked (+ 40) in Fig. 1, is the south edge of a segment of ore which has been followed northeasterly and upward for a few feet. The total movement of the north country, which has here been upon three, possibly upon four, presumably parallel fissures, indicated by this occurrence, is, as nearly as can be determined, about 400 ft. in the direction N. 45° W., at an angle of about 30° from the horizontal. The total vertical component of the above movement is about 200 feet.

The vein at point (+ 40) was found by drifting along the most northerly branch of the north fault and breaking into its hanging-wall.

The third ore-occurrence, sought for by raise at *C*, and found since the intersection-lines in Fig. 1A were outlined, is at Station *C*, in the raise from No. 8 level, at which point the intersection of the vein with a break was found 55 ft. above the level. Here also a normal segment starts off. Although it has been temporarily interrupted further north, by a reversed fault, it is without doubt a continuation of the vein from the northwest corner of the most easterly segment of the mine.

Opposite this point is doubtless a double fault with an intervening segment, as shown in Fig. 1A.

This ore-occurrence indicates a total movement of the northwest country N. 45° W., and at an angle of depression of 33°, of 420 ft., and a total vertical drop of about 220 feet.

The position of the ore at point *C* was therefore 20 ft. further in the line of the movement and had 20 ft. more vertical displacement than is indicated at the ore-occurrence at (+ 40) on the No. 4 level. It was, however, the probable extent of the movement, as indicated by the ore found at No. 4 level, that suggested the raise from No. 8 level by which the vein was recovered.

There are exposed in the stopes of the Berlin mine, many instances of breaks and faults, which fade or run out to nothing, one of which, not shown in the drawings, but clearly enough in evidence in the mine, is found in the southwest cor-

ner of the second stope from the east end of the field. In this case the break, normal in its planes, intersections, and in all other respects, begins with a mere seam in the foot-wall of the stope, increases for 20 ft. or so, to a point where the vein-displacement is about 4 ft., then decreases for 20 ft., to a feather edge, leaving no noticeable fissure beyond its ends in the roof or floor of the stope.

One is here impressed with the fact that fissuring and faulting is the habit of the rock-mass. In this connection is perhaps worthy of illustration an observation, shown by sketch in Fig. 5, of the freshly uncovered side of the No. 4 level then

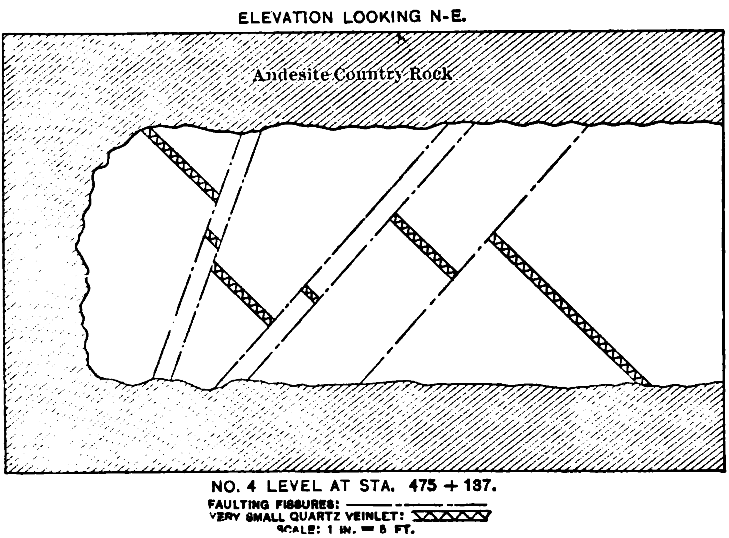

FIG. 5.—QUARTZ VEINLET, SHOWING NORMAL AND REVERSE FAULTING.

being driven. A quartz veinlet, about 1 in. in thickness, was in a few feet faulted normally three times, and by reverse faulting twice, between the roof and the floor of the level.

The bright, white quartz against the dark andesite told its story as though just from the press.

In Figs. 1 and 1A an attempt is made to show pictorially the underground works and stopes, and in the two together the relations of the works on the Berlin vein and the breaks and faults which have disturbed it. In this illustration all that is really known of the matter has been found in the underground works shown in Fig. 1. The structure remote from the under-

ground works is entirely assumption, based, as far as possible, upon the known ground as it existed in the middle of 1906.

From a practical standpoint, the extraordinarily disturbed condition of the rocks in the Berlin mine is very unfortunate. Without attempting to give details, it is evident that the prospecting and development of the vein in such a broken country must be unusually troublesome and expensive.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Comparison of American and Foreign Rail-Specifications, with a Proposed Standard Specification to Cover American Rails Rolled for Export.*

A reply by Mr. Albert Ladd Colby to the Discussion of his Paper printed in *Bi-Monthly Bulletin*, No. 13, January, 1907, pp. 113 to 132.

ALBERT LADD COLBY, New York, N. Y. (communication to the Secretary†):—I observed on p. 638 of the *Bi-Monthly Bulletin*, No. 11, September, 1906, that to obtain tenders from several American mills, the foreign engineer should modify his maximum phosphorus to 0.10 per cent., not as Mr. E. Windsor Richards quotes me, that no American rail-maker can produce rails under 0.10 per cent. of phosphorus. Mr. Richards claims that no English engineer would agree to accept 0.10 per cent. of phosphorus on any terms whatever. Mr. Webster writes that only after an engineer has been convinced that rails can be made in America equal in every respect to those he is getting abroad, should he be asked to modify any conditions in his specifications.

I know it to be a fact that during recent years in many cases, as, for instance, when delivery could be secured more promptly in the United States than in Europe, the consulting engineers of several British and colonial railroads have frequently agreed to modify their phosphorus requirement to a maximum of 0.10 per cent., and the rails delivered[1] under these modified specifications have, under like conditions, given just as satisfactory service and proved to be no more brittle than similar sections of 0.07 per cent. phosphorus rails, rolled in England under the same specification except without modification as to phosphorus.

Furthermore, it would appear from the analyses of British rails, quoted by E. A. Dancaster,[2] in his discussion of Mr.

* Published in *Bi-Monthly Bulletin*, No. 11, September, 1906, pp. 629 to 680.

† Received Feb. 13, 1907.

[1] See *Export Statistics*, p. 638.

[2] *Journal of the Iron and Steel Institute*, vol. lxviii., No. 2, pp. 343 and 345 (1905).

Thomas Andrews's paper on the Wear of Steel Rails on Bridges, that the limits of 0.06 per cent. in the older British specifications, and of 0.07 per cent. of phosphorus in the British Standards Committee specifications, quoted by Mr. Richards, are not lived up to by home mills.

I recommended a maximum of 0.10 per cent. of phosphorus in my suggested specification, which I have defined as a contract to be strictly lived up to, because it insures competition and because there is no evidence that the large tonnage of low-carbon American rails which have been exported have, because of a maximum content of 0.10 of phosphorus, instead of 0.07 or 0.08 per cent., failed or proved brittle after service. I freely admitted that phosphorus was the most undesirable constituent of steel, but, as Mr. Stead and Mr. York have pointed out, rail-failures are frequently wrongly attributed to the phosphorus-content, and, on the other hand, there is abundant evidence, such as quoted by Mr. R. Price-Williams, that the higher-phosphorus rails, of the lower carbon specified, have given excellent service.

I am glad that Mr. Price-Williams, whose first paper on the life and wear of rails was presented to the Institution of Civil Engineers in 1866,[3] and who has since devoted much time to the study of this subject,[4] supports my criticism that some of the drop-tests of foreign rail-specifications are disproportionate to the force of impact that the rail receives in service.

Also, that he calls attention to the analyses quoted in his paper,[5] showing that the lower-carbon rails of the British specifications had withstood eight years' severe service, although they contained 0.10 per cent. of phosphorus; and to the analyses of the Great Northern British rails tested by Mr. W. G. Kirkaldy,[6] which were in straight line track for 24 years and had withstood a traffic of 57,000,000 tons; the hardest of these rails contained 0.38 per cent. of carbon and 0.126 per cent. of phosphorus.

The knowledge of these examples of good service given by

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[3] *Proceedings of the Institution of Civil Engineers*, vol. xxv., pp. 353 to 428 (1866).

[4] *Proceedings of the Institution of Civil Engineers*, vol. xlvi., pp. 147 to 208 (1876); vol. cxxxvi., pp. 185 to 188 (1899).

[5] *Proceedings of the Institution of Civil Engineers*, vol. xlvi., p. 157 (1876).

[6] *Proceedings of the Institution of Civil Engineers*, vol. cxxxvi., p. 185 (1899).

low-carbon rails of British specifications containing, however, between 0.08 and 0.10 per cent. of phosphorus, and many others which might be quoted, prompted my remarks on the phosphorus-content, and warranted me, in the standard specification recommended to cover rails to be rolled in America for export, in saying that the phosphorus could be 0.10 per cent. as a maximum, thereby permitting tenders to be made from all American rail-mills.

Although appreciating the force of Mr. Price-Williams's remark that, from the point of view of the railroad company, the matter of greatest importance is the longest wear without the danger of brittleness, this subject could not be touched on, because the paper was confined to a comparison of current rail-specifications, in which no requirements as to wear and life are included. A number of references to the wear of rails were, however, purposely included in the Bibliography supplementing the paper.

It was for this same reason that the important questions raised by Mr. Lamberton and Mr. Freir, and other questions, such as hammer-hardening, etc., could not be included within the scope of the paper.

It was also unfortunate that no reference could be made in the paper to the experimental use of rails of special composition, such as very high carbon basic open-hearth rails, or the alloy steels containing either nickel, chromium or manganese, and the results of which trials I have watched with much interest.

Mr. Harbord's remarks on the different degrees of hardness in open-hearth and Bessemer steel of like carbon are pertinent and should be borne in mind in drafting individual specifications.

In answer to Mr. Hadfield's question as to the chemical composition of American rails withstanding certain drop-tests, I refer him to Table III. of my original paper, and for the drop-test and composition in the recommended specification to Tables VII. and VIII. It seems to me that the required impact-tests of Table VIII. form a safeguard against the brittleness feared from the recommended upper phosphorus limit of 0.10 per cent. in the steel.

In suggesting that I should have recommended 0.07 or 0.08

per cent. of phosphorus so that the manufacturers' desired leeway will result in furnishing no steel of more than 0.10 per cent. of phosphorus, Mr. Stead overlooks the emphasis which I placed on the fact that the suggested standard specification must be strictly lived up to, and that the maximum allowable phosphorus must be 0.10 per cent. I am glad Mr. Stead speaks of high manganese as a frequent cause of brittleness. I have analyzed more than 200 broken rails in which I found the manganese to exceed 1.20 per cent.; in the recommended specification the highest allowable manganese, in the heaviest sections, is 1 per cent.

I am pleased to hear Mr. York, who has had so long a rolling-mill experience, lay such stress on the relation of section to finishing-temperature. Mr. Webster and Mr. Kenney criticise my omission, in the recommended standard specification, of clauses fixing a maximum shrinkage-allowance after hot-sawing, and a maximum camber for rails at the straightening-presses. Such restrictions are out of place in a specification recommended as a general standard for all shapes and weights of sections. They are justifiable as addenda to the specification when it is applied to a certain section, but even then some leeway must be given to allow for the difference in the method of rolling at each rail-mill. This answers Mr. Palmer's question about a definite specified shrinkage. Mr. Palmer overlooked clause (*f*), page 664, when he said that finishing-temperature was not touched on anywhere in the paper.

I am glad that Mr. Webster includes in his communication a concise review of the present main points of difference between the rail committees of three American societies, because, as I confined my comparisons to the requirements of the current standard and individual rail-specifications now governing the rolling of rails in England and the United States, I purposely omitted two of these specifications. The president, Mr. R. W. Hunt, in his brief remarks closing the oral discussion of my paper, observed that the report of one of these committees had not yet been accepted—that of the American Society of Civil Engineers; to this he might have added that the rail-specification of the American Railway Engineering and Maintenance of Way Association had not yet come into use.

I am of the opinion that the reason given by the engineer-in-

chief of the Paris and Orleans Railroad for the omission of all chemical requirements from his rail-specification—namely, that accurate analyses, other than carbon, cannot be made without retarding manufacturing operations—would be warmly disputed by the chemists of French rail-mills. In American mills no difficulty is experienced, with an output of 2,200 tons of rails per 24 hr., in obtaining accurate determinations of carbon and manganese on each heat, phosphorus on six heats every 12 hr., and an average silicon and sulphur on each 12-hr. rolling.

Mr. Sauveur calls to account the makers of rail-specifications for not demanding that the impact-test shall always be made on a piece cut from a rail coming from the top of the ingot. In my recommended standard specification I leave the location of the test-piece an open matter to be settled between the inspector and the manufacturer. In my observation I have never seen any objection raised by American rail-makers, if the required height of drop is reasonable, to testing pieces of rail, or in practice usually rail-butts, cut from the top rail of an ingot. In July, 1905, at the eighth annual meeting of the American Society for Testing Materials,[7] at which Mr. Sauveur as well as many representatives of rail manufacturers were present, a standard rail-specification was adopted, in which it was specified that the drop-test shall be made on pieces from 4 to 6 ft., "taken from the top of the ingot."

Mr. Palmer raises the commercial question, often discussed, of the right of a manufacturer to invoice rails at actual weights when he has kept within the allowable variations from templet recognized as good rolling-mill practice. The allowable percentages of short rails and the number of second-quality rails for use at stations and in sidings and yards are also commercial matters for individual adjustment. The recommended specification, in these regards, was based on American practice.

A personal inspection of American mills furnishing rails for export would completely satisfy Mr. Palmer on the question of drop-tests and the requirements of the recommended specification as to check-analyses and inspection, for, as I have seen them interpreted by American mills, there is no just ground for complaint.

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[7] *Proceedings American Society for Testing Materials*, vol. v., pp. 32, 43 and 47 (1905).

Mr. Kenney refers to the testimony which has been furnished to the American Society of Civil Engineers and the American Railway Engineering and Maintenance of Way Association, showing that nearly every American railroad having heavy traffic is suffering greatly from broken rails. He states that this brittleness is due to phosphorus in the higher-carbon rails now ordered by American railroads, in their attempt to obtain increased wear under present heavy traffic conditions.

This criticism of 0.10 per cent. of phosphorus in the American high-carbon Bessemer steel rails does not apply to the maximum limit of 0.10 per cent. of phosphorus in the lower-carbon steel included in my recommended specification for rails rolled by American mills for export. I have referred elsewhere in this reply to Mr. Kenney's criticism, as to the absence in my recommended standard specification of a shrinkage-clause, and of a clause specifying a definite maximum camber for rails at the straightening-presses.

It was not from ignorance or from lack of appreciation, as assumed by Mr. Kenney, that I omitted references to the present American conditions touched on by him, but simply because my paper was confined principally to a criticism of foreign rail-specifications governing the manufacture of lower-carbon acid Bessemer steel.

Mr. Kenney declares that "the brittle rail is one of the most important subjects before American railroads to-day." He also says that "the rails (meaning American acid Bessemer rails) are not giving satisfaction as to wear; and any attempt to improve the wear by making the rails harder is met by a crop of brittle rails."

He remarks that this "brittleness is caused by high phosphorus." I think high phosphorus is one of the causes, but if it is a fact that the "brittle rail is one of the most important subjects before American railroads to-day," then the real cause of the trouble is that the railroads have continued to attempt to obtain better wear, by asking the makers of acid Bessemer rails to put more carbon in the steel, instead of benefiting by their own first experience with brittle rails and by the advice given them by the manufacturers, who are dependent on ores making acid Bessemer steel between 0.08 and 0.10 per cent. of phosphorus.

Mr. Kenney asserts that rails with lower phosphorus and much higher carbon have shown much better wearing qualities without being brittle; he here refers to some experimental high-carbon basic open-hearth rails, now on trial. It will be some time before the ore-conditions of the United States are such that none of the American mills can make acid Bessemer steel rails under 0.10 per cent. of phosphorus. I venture to suggest that this interval of time can be advantageously spent by the railroads having heavy traffic in making experiments to improve the life of the rail, other than by simply increasing the carbon-content.

In a recent address[8] before the Merchants' Club of Chicago, Mr. James J. Hill, President of the Great Northern Railroad, in speaking of the railroad conditions in the United States, stated:

"I have noticed that from 1895 to 1905—ten years—the growth in ton-mileage was 110 per cent. The growth in the mileage of railroads to handle that traffic was 20 per cent. . . . In ten years the railroads of the country expanded 20 per cent. for the handling of a business that increased 110 per cent. . . . It is estimated that from 115,000 to 120,000 miles of track must be built at once to take care of this immense business."

During the ten-year period referred to by Mr. Hill the American railroads have not increased the sectional area or weight of their rails more than 25 per cent., and they have tried to make up this great deficit between immense increase in tonnage on one hand and small increase in trackage and in weight of rail on the other hand, by simply demanding acid Bessemer steel rails higher in carbon.

They have evidently, according to Mr. Kenney's statements about broken rails, passed the limit of safety.

In a letter which Mr. Hill sent to the Governor of Minnesota on January 14, 1907, he gives the following exact data compiled from the official reports of the Interstate Commerce Commission, which further emphasize the greatly increased wear to which rails are now subjected:

	1895.	1905.	Increase.
			Per Cent.
Freight ton-mileage	85,227,515,891	186,463,190,510	118
Passenger mileage	12,188,446,271	23,800,149,436	95
Total single-track mileage	180,667	218,101	Only 21
Number of locomotives	36,699	48,350	35
Number of passenger cars	33,112	40,713	23
Number of freight cars	1,196,119	1,731,409	45

[8] *Railroad Gazette*, vol. xli., p. 441 (1906).

Mr. R. Price-Williams, an authority on the wear of rails, in his able discussion of my paper declares:

> "There can be no question that the wear of steel rails subjected to the destructive effects of the great increase in the weight and speed of the main-line traffic of the principal railways in this country is far greater than is generally supposed."

He observes that the annual cost of maintenance and renewal of the London & North-Western was one-seventh of the entire working expenditure.

It certainly appears from these statements that the question of the maximum service safely obtainable from a rail must be looked upon broadly and studied seriously. The rail-maker must do his part; but the railroads, in view of the present serious traffic-conditions, must be willing to experiment on a large scale in order to determine whether a greater initial cost of the rail, by either increased section, special composition, or both, is not economy in the end.

Until a general change in American methods of rail-manufacture takes place, it appears to me, from the discussion, that the proposed standard specification will, if strictly lived up to, form the basis of a contract under which American mills will furnish a safe rail for export and one which will give as long a life in service as rails of British make.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Ore-Deposits of the Joplin Region, Missouri.*

BY F. L. CLERC, DENVER, COLO.

(New York Meeting, April, 1907.)

THE lead and zinc region of SW. Missouri is interesting, not only by reason of the value of its output, which ranges in the neighborhood of ten million dollars a year, but even more because of the facilities which it offers for the study of certain forms of ore-deposits, of which the *loci* and genesis are somewhat obscure. Although the mineral species found in the region are few and of common occurrence, crystallization has taken place on a generous scale, and unusual forms abound in many combinations, presenting examples of pseudomorphism, paragenesis, metasomatic replacement and the action of mineral-depositing and mineral-dissolving waters. For the mineralogist, lithologist, and specialist in certain lines of metamorphism, it has peculiar attractions, while the systematic geologist will perhaps find its chief claim to attention in the simplified problem it presents, in the study of ore-deposits. In addition to the phenomena above enumerated, it presents instances of well-developed comb-structure in the ores, fissures and faults, and slickensides—features usually associated with extensive movements in the earth's crust, and believed by some authorities to prove the deep-seated origin of the ores. In connection with these occurrences, the absence of all igneous rocks from this region is noteworthy and significant. For that reason, the simplified case presented by the Joplin region, from which these rocks have been eliminated as a factor, is specially valuable.

Having had unusual opportunities to watch the development of this district, I have been deeply interested in the bearing of the revelations of the Joplin mines upon questions of universal importance to the science of ore-deposits; and it was to my great regret that the project of a meeting of the American Institute of Mining Engineers at Joplin, proposed in 1892, was

* SECRETARY'S NOTE.—This paper was accepted Sept. 4, 1906.—R. W. R.

found to be impracticable. Such a meeting would have given to many experienced field-observers an opportunity to see for themselves many things which they cannot so clearly recognize or so decisively judge at second-hand through the descriptions and arguments presented in this paper.

The authority which Posepny has given to the theory of the deep-seated origin, and the deposition by ascending waters, of all sulphide ores, has without doubt enlarged our outlook, by constraining us to pause and review the evidence. His definition of "ascending waters," seems, however, in a final analysis, to reduce itself to this—namely, "those which deposit sulphides," and that of "deep underground circulation" to the water below the "zone of oxidation." His term "Barysphere" seems to imply, that because the average density of the earth has been proved to be more than double the density of any sections of it that are open to observation, therefore towards the center of the earth there must be accumulated a preponderance of the heavier metals. His words, in the translation, are "that is to say, the deep region is the peculiar home of the heavy metals."[1] While this surmise may be correct, I think few geologists or mining engineers will admit that it has much weight in the argument. Generalizations are useful only when they do not require the ignoring of essential facts. The paper of Chas. R. Keyes,[2] presented at the Mexican meeting of 1901, states the case strongly against such hasty generalizations.

The secondary enrichment of certain portions of an ore-body can often be observed in the development of a single mining district. The theory by which it has been explained[3] leaves little to be desired. It was a brilliant generalization, and I think one of the most important contributions, so far as immediate results are concerned, that geology has recently made to mining. Where this enrichment is confined, as it were, to a single set of apparatus, presented by natural conditions, its successive stages can be observed and proved. Such a migration of an ore body, or of any of its constituents, may be likened to

[1] *Trans.*, xxiii., 247 (1893).

[2] Diverse Origins and Diverse Times of Formation of the Lead- and Zinc-Deposits of the Mississippi Valley, *Trans.*, xxxi., 603 to 611 (1901).

[3] *Trans.*, xxx., 27 to 177, 177 to 217, 424 to 448, in the contributions of Van Hise, Emmons, and Weed (1900).

the movement of a whiff of steam, a wreath of smoke, or a flock of grasshoppers. The motion of the separate individual particles of which it is made up cannot be followed; but the resultant motion of the mass is evident, and the mass preserves definite outlines. The idea is so suggestive that it may lead us far afield, and I think there is danger in speculating over too wide a range. If we should call some observed concentration, the mth, and another, that could be proved to be later, the $(m+n)$th enrichment (bearing in mind always that it might be accompanied by x impoverishments elsewhere), it would be seen at once how indeterminate the problem may become. I shall make no application of this theory in the present paper, although there are cases observable in this district to which I think it will strictly apply.

Much has been written of the Joplin district. My statements are confined mainly to the area bounded on the north by Center creek, and on the south by Shoal creek, and especially to the high rolling prairie-lands between these streams; but I believe that many of my deductions are applicable to a much more extended area. Standing on one of these uplands, and looking towards either of the creeks, one sees that the ground slopes, at first gradually and then quite abruptly, to a nearly level bottom, through which the creeks wind, and that it rises beyond the creeks to the general level of the high prairies. These valleys are largely the work of erosion, and the bottoms are much wider than is required by the volume of the present streams, even in flood. There is evidence, in many places, of the filling of the bottoms by detrital material, and, in some places, of the raising of the bed of the creek-channel besides. Instead of a single bluff between the prairie and the bottom, there is often a strip of rocky and broken ground, sometimes several miles wide, consisting of ridges, intersected at frequent intervals by cross-valleys, which meet at the ridge-line and depress it, but discharge in opposite directions. These strips of rugged country are covered with a dense growth of black-jack oaks, and are marked "timbered" on the earlier Land Office maps. The exposures show generally chert and bright red clay; and where the strata are not horizontal, they dip, seemingly, in all directions. Erosion by

surface-water and accumulations of local drift are much in evidence. It is difficult to trace any evidence of faults.

For a proper understanding of the problem to be discussed, it is necessary to state concisely the system under which mining has always been conducted here, and to indicate the unexpected difficulties, arising from this system, which must be encountered by any student of that problem.

As a rule, the owners of land in this district, known or supposed to contain mineral, do very little which can be called mining. They lay it off into mining-lots, or lease it to so-called mining companies, who then sub-divide it. The work carried on by these companies usually consists in sinking a number of pump-shafts, and in putting in and operating pumps. On the surface they furnish water to the washing-plants. By the terms of the mining-rights granted (that the lot shall be worked in a "miner-like" manner, I believe the phrase is), they have, but seldom exercise, an indirect control of underground work.

Custom has fixed the size of mining-lots at 200 ft. square—less than one acre each. They may be "registered on" by any individual or partnership acceptable to the company; and such registration secures, not a sub-lease, but a "mining-right." The distinction is important. The rights are forfeitable by failure to prosecute work, or to comply with the terms of the owner or company, and are granted for a fixed period. It is held that the ownership of the ore remains with the grantor. He has the right to say to whom it may be sold, and at what price; to have it weighed on his own scales; to collect the purchase-money, and to deduct his royalty, and (if he runs pumps) his "pump-rent"; and the remainder he pays over to the registered occupant of the lot, or his agent, as "the contract-price for work done." In practice, the rigor of these contracts is somewhat abated. The equitable claims of the miners are considered, in privileges of renewal, preference in registering on adjoining lots, and other ways. Most mining partnerships are unincorporated, but of late years a number of incorporated companies have taken formal mining-leases on several mining-lots, from the owner or original lessee, and have made special terms. The success of these corporations has not been conspicuous. Under the system by which the

district has been developed, and which is still prevalent, the party mining the ore must first find it and then extract and prepare it for market. He sinks the shafts, runs the drifts, puts up hoisting-machinery, and crushes and cleans the ore, at his own cost. Notwithstanding these onerous conditions, many a comfortable fortune has been made by miners from a single lot.

The owner or the leasing company marks the lot lines on the surface, but does not take much trouble about underground lines. Miners on adjoining lots must settle these matters among themselves. Sometimes litigation results; but usually a tape-line is sufficient to adjust matters, though occasionally a surveyor is called in. Naturally, a miner who has found good ore is anxious to take out as much of it as possible, and therefore leaves the necessary supporting pillar on the next lot. It is etiquette, in visiting a mine, not to ask where the line is, and not to seek to know the course of the ore, or the point of the compass to which a drift is running. I have examined hundreds of working-places, often when I did not know the miners, and can recall only a single instance in which I was refused permission to make an examination.

The defects of this system are glaringly apparent; I have elsewhere[4] pointed out a few of the less obvious elements of strength and elasticity which it undoubtedly has exhibited. The defects involved the failure of the system to develop the mines thoroughly and systematically, and to preserve any record of what has been taken from them, and what has been left. This failure explains one of the many difficulties which attend the study of the district, and may excuse, to some extent, a certain vagueness in the report of some of my own observations—a vagueness which cannot be avoided, in cases in which no measurements were taken, or records kept, or when the evidence has been destroyed, and contemporary witnesses cannot be found. There is, in general, unquestionable danger that, because of the lack of records of old workings, the study of deposits now being mined may fail to disclose the relation which once existed between these deposits and those which were worked long ago, and that, from observations so limited and

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[4] *Mineral Resources of the U. S.*, U. S. Geol. Survey, vol .i., pp. 368 to 373 (1882).

widely separated, conclusions not sufficiently comprehensive may be drawn.

The theory here advanced to explain the origin and form of the lead- and zinc-deposits of the Joplin district, was first suggested by me in a little sketch of the district written in 1887, to encourage Mr. John N. Wilson in the publication of statistics which he had collected, covering the production of the region by companies and mining-districts, for the year. From his beginning can be traced the regular weekly publication of these statistics, which has come to be taken as a matter of course.

This theory may be summarized as follows:

1. The location of the principal ore-deposits of the Joplin district is due to a system of surface and underground water channels, which was once much more closely connected with the surface-drainage than it is now.

2. The agency which diverted the surface-waters from these old courses was geological and not chemical.

3. This diversion has been effected within comparatively recent times, long since the close of the Carboniferous age.

4. The ores, as we now find them, were deposited after the surface-waters had been largely excluded by mineral-bearing-waters, which found access to these old channels, and a retarded passage through them.

5. This old system of surface and underground drainage is strictly analogous in form and origin to the present drainage-system, but entirely distinct from it.

6. Where the later system intersects the ancient system, surface-waters have rapidly cut out and dissolved the ores.

7. The ore-bodies of the region form a true system of connected and ramifying ore-veins, presenting as definite a problem for study as do the surface and underground streams of the present day.

In the lack of precise data, I do not expect to prove these theses rigorously; but if I succeed in making them appear probable, it may be hoped that the combined investigations of the U. S. and State geologists, with the co-operation of mine-owners and miners, will bring together a mass of evidence which will be decisive one way or the other. If the theory is not true, the sooner it is discredited the better for all parties

concerned. If it is true, and if it be followed out to its logical conclusions, it may lead to important developments in the region.

Mr. Schmidt,[5] in his report of 1874, has noticed "that the principal ore-deposits have not been found on the larger streams, but on their smaller branches." Let us follow one of these smaller branches across the broken ground, beyond the point where it shows surface-wash and carries water all the year round, up and onto the high prairie ground which includes the true water-shed. After leaving all traces of surface-wash, shown in the dry gullies from which the soil has been removed, we are still able to follow a slight depression of the surface, through which the surface-water runs off. Following carefully one of these minor valley-lines, we notice similar slight depressions, coming into it from both sides. Following any one of these will bring us to the actual top of the high prairie, forming the divide between adjacent creeks. There we shall find a more or less level expanse, which appears to maintain a uniform height above the water in the larger streams. Drill-holes in this area will encounter a larger proportion of flint, and therefore a smaller proportion of limestone, in some places than in others, and will often go down many times the depth of the deepest shafts in the district, without striking ore-deposits or broken ground. This difference in the amount of flint may be due either to the persistence of local colonies of silica-secreting organisms, during the long periods in which the Mississippian series was being laid down, or to local deposits of siliceous materials in shallow waters, closely analogous to the sand-bars which we to-day find in muddy bays, the channels between which are filled with lighter limy silt. However they may have been formed, these cherty ribs are an important feature of this geological formation. They must have had from earliest times some effect in determining the lines of fracture in these strata, and some influence on the subsequent erosion. It is probable that this effect has continued down to the present day.

A shaft, now sunk on the slope of one of these upland swales

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[5] The Lead and Zinc Regions of Southwest Missouri, by Adolf Schmidt and Alexander Leonhard, *Report of Missouri Geological Survey*, pp. 381 to 502 (1873–4).

will probably strike, below 20 ft. of soil, gravel, much altered chert and clay, a solid surface of limestone. On the top of this limestone, there is likely to be a thin film of water, scarcely enough to wet one's fingers in, but sufficient for the prairie "cray-fish," which bore to the surface from the shallow pools which collect in depressions, and sufficient also for domestic use. This is the true well-water (*l'eau phreatique*) of the upland prairies. The dip of the limestone will conform to the slope of the topography. If it is followed down by an incline drift, or by trial shafts, it will be found to reach its lowest point nearly under the valley-line, at which point there will be one or more cracks, following the course of the valley. By drifting along the top of this limestone, in either direction, at right angles to the valley-line, another parallel break will be found, nearly under the point where the slope meets the plain above.

A topographic map on large scale would show that the valley lines have a dendritic arrangement, and that the smaller twigs of neighboring branches interlock. A simple rumpling across a line of stress, will not suffice to explain these observed surface synclinals. They suggest rather a marginal puckering around a central dome. It is not difficult to imagine a force, acting within the earth's crust, which might have this effect; but in view of the short wave-length—that is, the small distance from crest to crest—of this contorted limestone, such an explanation is not satisfactory. Another shaft, sunk at a point beyond which none of these lateral branches can be traced, may very likely show a very slight saucer-like depression, scarcely visible at first sight. A shaft so located is almost certain to be on a "water-hole." Instead of solid limestone, it encounters broken limestone, in the form of fragments, much decomposed on the surface, and, between them, crevices filled with clay. When chert is found under these fragments it usually retains its position in the stratification, but is broken through transversely, so that it can be taken out without blasting. Thinner strata of limestone, between flint layers, are not only broken into fragments, but are actually perforated by water dropping through the flint strata. From a single shaft, I have seen half a dozen or more of these perforated masses, some of them too large to go into the hoisting-tub, sent to the surface by hooking the rope through the holes. Here we have evidence of the

excavating work of underground water, and the suggestion that it may have brought about the subsidence of the surface rocks to produce the synclinal troughs above observed. Without doubt, this work of dissolution and abrasion, acting for a long time, would remove enough material from the lower strata to cause the upper strata to settle down. The fewest number of fractures which would enable a solid ledge of rock to accommodate itself to this lower level, would correspond to the three lines of break already observed. The first point to be made clear in this connection, is that the material removed has not been taken from any one channel; it has been leached or washed out from all parts of the mass accessible to the water within this limited water-shed. The chief line of attack of this water has varied from time to time, and its effect was measured by its volume and its dissolving efficiency. It is not probable that a cavity existed at any time, at all corresponding to the amount of material removed.

This operation of weathering throughout a mass, either above or below ground, can be observed in the shrinkage of an old mine-dump. Originally it had sharp outlines, and was composed of pieces of different size, hardness, and solubility; but after a few years' exposure, the track is twisted out of shape, the general height is diminished, lighter materials have been carried away, and even the harder have begun to crumble. After one generation, only its broken and scattered skeleton may remain to mark its site. A still better illustration, perhaps, is the melting of a snow-pile between street and sidewalk, where the ice-sheets are the last to disappear.

In addition to the solid material dissolved or carried away in suspension by these underground waters, there are actual flows of soft mud from a higher to a lower level, which are too commonly observed in this region to permit doubt of their effect in producing local subsidence of the surface.

Upon the reasonable assumption that one underground stream, traced as above described, is representative of others, there is such a stream corresponding to each of the branches of the wet-weather surface-flows; and these underground streams constitute a system closely related to the surface-system.

A roof requires a certain thickness to support itself. In following one of these underground streams, a point is reached

where it forms a true cave, either because the roof has become self-supporting, or because the stream finds an open course through the ridge which divides it from its neighbor. On following it still further, evidence may be found that the roof has fallen in; or, in other cases, that a surface stream has cut into the underground channel. In either event, accumulations of much mingled *débris* will have resulted; and it is often not easy to distinguish between the work done by underground and by surface streams, respectively.

One further point must be noticed in passing—namely, the effect of open cavities in preserving the ridges and higher ground from disintegration and weathering, by rapidly draining off from them the surface and dissolving waters. They have also a similar effect in protecting the ores in the higher ground.

In following a little further the course of these streams I shall call them the "shadow-streams" of the surface drainage-system, not because I think this is a name which should be retained, but because it will help me, in the absence of a diagram, to picture actual conditions. The shadow of an object does not have the same form as the object itself; its lines are shortened or lengthened, thrown to one side or the other, or even reversed, according to the position and form of the surface which receives the shadow. The shadow-streams are thrown on whatever surface is impervious enough to carry off their water. If this surface rises or falls, or inclines to either side, the shadow-streams will be correspondingly distorted. It should be noted, that while a surface-stream or run-off has normally four directions of possible movement—forward, downward, to the right and to the left, an underground stream, if running full, has two additional directions—upward and backward. If a tree represents the surface-streams, we must choose, to represent the underground streams, a tree on which the branches join the stem at all angles. Evidence of the existence of these shadow-streams (some of which had a continuous flow before pumping became general) is found in all the camps of the Joplin district. In some cases it is possible to explore the caves through which they run, to study their configuration and its causes.

The shadow-streams of the present surface-drainage do not,

in general, contain ore-deposits. They are interesting by reason of their striking similarity in form (suggesting a similarity of origin) to an older system of shadow-streams, connected with an older surface-drainage, which does contain mineral deposits.

The regimen of rivers, streams, and mountain-torrents, and their agency in shaping topography, has been much studied; an elaborate classification has been made; and an extensive vocabulary has been invented or adapted to express their present and past stages. The work of underground streams might be similarly described. But as the amateur trout-fisherman does not need to know anything of this classification or vocabulary in order to make a shrewd guess, several hundred yards before he comes to it, on which side of the stream the next deep pool will lie, or where he will find the head, and where the tail, of a riffle, so the mining engineer, following one of these underground streams, by noticing its rise and fall, the material cut through, and the inclination of the strata, can foresee on which side will lie the accumulation of *débris*, and on which the open channel. Moreover, as the fisherman, so long as the trout rise, and he does not meet with "No Trespass" signs, does not worry about the continuation of the stream, and would say, if asked, "It probably starts small somewhere, and eventually reaches the ocean;" so the miner, as long as he finds ore in these channels, and keeps on his own property, does not worry about the continuity of the channel.

I explored one of these caves on the Hopkins farm on the north side of Turkey creek, four miles east of Joplin. It had been stopped up for several years, and I hired a man to dig it open. His shaft was sunk at a point he had marked about a third of the way down the slope of the hill on which the house stands. It struck the cave at a point where it makes a right-angled turn to the west. I followed the longer branch in a northerly direction, and came, a little way in, to a clear stream of running water, a foot or more wide and an inch or two deep. For some distance, the roof was generally flat, and high enough to permit me to walk erect. The nearly vertical left wall was made up of horizontal layers of alternate lime and flint. The right wall was concealed by a thick bank of tallow-clay, which sloped from the level of the roof on the right down to a nearly

vertical cut, made by the stream in its foot. The clay had the consistency of lard, and had retained with absolute fidelity the impressions made upon its surface by the tools, clothes and fingers of the men who had visited it several years previously—showing that the water had not risen much, and that the drip from the roof was slight. The stream flowed over a bed of the same clay, and some of our steps sank into what appeared to be cracks in a rock floor.

The cave made numerous and short turns; and I noticed horizontal cracks, formed by the spreading apart of two layers of chert, extending under the roof and into the right wall, almost continuously, as far as we were able to penetrate. These gaping cracks seemed to narrow as they passed in; but our lights could not penetrate to the end of them. In places the cave was filled almost to the roof with fallen slabs of chert. Some of these still hung at dangerous angles, attached to the roof near the right wall, and it was rather a ticklish matter to crawl through the small openings left, and not brush against them. We passed through several of these openings where, of course, we lost the stream, and came to wider places where we found it again. In one or two other places the stream disappeared below the floor; but it reappeared again and continued to within 40 ft. of the end of the practicable opening.

I squirmed along like a lizard for the last 30 ft., hoping to find an enlargement beyond. At this point the flat opening under the roof extended across the width of the cave, into the walls on both sides, and ahead further than I could see. When I twisted around to crawl out, my candle was extinguished; my matches were wet; and I could rely only on the sentry whom I had posted to guard his light at the point where I had left the stream. In spite of my shouted caution, he began to trim his wick and thus put his candle out. Either his matches or his clothes were wet; and he could not get another light. However, we had only to find and follow the stream, and it would take us to daylight. So one of us was posted where we lost the stream, and the other crawled up and down until he found it again. In this way we worked our way out in the course of two hours, wet through and plastered from head to foot with tallow-clay.

After procuring dry matches, I explored the west branch,

which was short. Near the end I found that the stream dropped into a lower chamber, which extended back under the floor of the larger cave. The dimensions of this chamber were about 6 by 8 by 3 ft. Dropping down into it, I saw that the stream ran into a hole in its floor. The probable junction of this stream with Turkey creek is a spring about a quarter-mile from this point.

My examination of this cave was not as thorough as I had hoped to make it; but it was satisfactory to a certain extent, in that no trace of mineral (unless the tallow-clay was zinkiferous) was found and I saw no incrustations of any sort. The fractures of both limestone and flint appeared fresh and but little corroded. In every other respect, so far as I could see, the cavity was completely like many which I had found filled with ore. The horizontal openings between flint layers in the right wall and at the end, if they had been filled with zinc-blende or blende-bearing material, would have been the counterparts of the "hard sheet-ground" elsewhere mined. The point worthy of particular attention is, that if these gaping openings had been encountered in a shaft, only a few feet away, the existence of the cave might not have been suspected, and it might have been difficult to explain how they had been produced. I can only estimate, in a general way, that the length of the cave explored was about 200 yd. (The popular estimate is several times greater.) But, judging from the topography of the country, I have no doubt that this cave has direct connection with an underground stream which I struck in a shaft more than half a mile to the northeast.

I could mention many other caves similar to this one, with water flowing through them, and all barren; but I do not know of any that have been surveyed, and I cannot give a more definite description of any of them. I will cite only two; and these can only be called caves upon the assumption that a number of horizontal openings between flint layers are the equivalent of a cave, and form, in fact, a section of its length.

The first is under the natural cut of which the Missouri Pacific and the Kansas City, Fort Scott and Memphis railroads take advantage, in going from Joplin to Webb City. Here an underground stream has largely done the grading for the railroads. In 1892, I sank a shaft a few feet east of the railroad right-of-way, and was obliged to put in, at the depth of 18 ft.,

a pump, which was 12 in. in diameter with 6-ft. stroke. When it began pumping the working-barrel projected above the surface of the ground. A second pump of the same size was soon required, and the two had to be run continuously, night and day, at 22 stokes and upwards a minute, to hold the water down. The ground was broken flint and clay, and the water, which came always from near the bottom, was usually clear and potable, but filled with almost invisible spangles of bisulphide of iron (probably marcasite), which danced in the tank like motes in a sunbeam, and gilded with "fool's gold," for a quarter of a mile beyond, the bottom of the ditch that carried off the water. A little blende, in small crystals, was also found. When I last visited Joplin, seven years later, there were several productive mines working on both sides of this draw.

The other underground stream which I would mention was struck by a drill-hole near the center of the tract owned by the Center Creek Mining Co., at Webb City. This stream was so strong that it swept away all the cuttings of the drill. The water did not rise to the surface or (apparently) get to the main pump-shaft, only 200 yd. away. The mine-water of the district is too acid for use in boilers; but this stream, which passes among the mines but not through them, furnishes water of satisfactory quality, which has been substituted in boilers for city water, with a considerable economy.

A long chapter might be written on the mine-waters of this district, and the incrustations in the old workings. Unfortunately, I can cite no analyses, and do not know that any have been made. I saw the column of a force-pump, 10 in. in diameter, which had been taken out of a shaft at Webb City, and which was almost closed by a deposit looking like a mixture of clay and iron-rust, though the iron of the pipe was apparently not much affected. The pump had been running continuously, but slowly. The opening left was only 3 in. in diameter. On the other hand, in some of the mines of the district, a shut-down for a single week means that the mine-rails will be eaten through in the web, and picks and shovels ruined, and that a new clack-valve, if of iron, will not last long enough to unwater the mine. This sudden corrosion, which does not occur while pumping is continuous, shows the results of exposure to air and the action of oxidizing waters. Perhaps such phenomena ex-

plain in part the legendary "Kobolds" of the German miners —malicious spirits, who work in the dark, hurry away exposed treasure, to be hidden and sealed up in safer vaults, and leave in its place worthless trash; who lose no opportunity to steal the miner's tools, and damage his property as much as possible. What is more important, this rapid oxidation may represent the first step in the process of secondary enrichment.

A system of underground water has been compared to a city's water-works, including the water-shed, storage-reservoirs, filter-beds, mains, laterals, house-connections, sewers and sewage-disposal works. For more complete analogy, we might interpolate two additional items—namely, the connection of a water-supply with steam-boilers by means of injectors (representing local solfataric and fumarole action in nature), and the connection with laboratories and chemical factories, for the production of comparatively pure mineral substances. It is to this last diversion of the water-current (which, in the case of a city, would probably amount to only a fraction of 1 per cent. of the total consumption, and, in the case here considered, will not be relatively larger) that particular attention is here directed.

It must be remembered, however, that in the underground water-system of nature there are no valves to be opened and shut. The water is always running. If the reservoirs are not emptied, it is because water is flowing into them at least nearly as fast as it flows out. Dams may give way; mains may cave in or be washed out; smaller conduits may be choked or otherwise thrown out of use; new connections may be made; and the level of waters in the reservoirs may rise or fall. The flow is always subject to hydraulic and hydrostatic laws. Efficient head, cross-section and friction control it. I cannot conceive that capillarity has any directive force when the capillary tubes are filled with liquid and both orifices are wet. Under these conditions it is simply a retarding force, like friction, which can diminish the velocity of the flow of a liquid, but, if time or area be varied in reciprocal proportion, cannot prevent ultimate movement. I find no difficulty in the way of water penetrating into cavities already full of water, provided there is a chance for an equal amount of water to escape, against a lower pressure, in another direction. Permeability is relative. Small leaks may be neglected in considering large flows; but this

does not prove that the leaks have no effect. A rock containing but a few hundredths or thousandths of 1 per cent. of hygroscopic moisture may yield a highly concentrated solution, if this water be displaced by slow filtration. Chemical activities, known and unknown, play their part; but I have always thought that water-deposited minerals have been placed where we find them by vein-currents of water which, by reason of their differentiation from the circulation in the adjacent barren country-rock, have become more fully saturated with mineral salts.

Whether such currents be "ascending" or "descending," appears to me a question of relatively small importance. If this small fraction, either of the annual rainfall or of the artesian supply, which can act in a certain district, circulates slowly through beds containing even traces of vein-minerals, and finds its way into any open cavity, such as an old, disused, and partially choked system of underground water-courses, I think the conditions are furnished for just such deposits as are found in the Joplin district. If, on the other hand, it discharged into flowing streams, there would be dissipation, instead of concentration, of its mineral contents.

Mr. Schmidt, in his report of 1874, has described certain residual clays which can be identified throughout this region; and his explanation of them, as formed *in situ* by the undissolved residues of limestones and cherts, is not likely to be questioned. The tallow-clays, which are often zinkiferous, and are generally found associated with oxidized zinc-ores, have been analyzed, and were probably formed near where they are now found. The clay called "gumbo" is generally found in shallow basins, and perhaps never exceeds 10 or 15 ft. in thickness. It is generally mottled, shows ocher-yellow, purple and white colors, and looks much like the coarser kinds of Castile soap. When a miner encounters it in sinking a shaft, he discards pick and shovel, and cuts it out with mattock or axe. It closely resembles in appearance the gumbo which lies a short distance above the upper coal-bed of Pittsburg, Kans. The black shale (which I have elsewhere called "slate," that being the name given to it by the coal-miners when it occurs over coal) is found under widely differing conditions. Sometimes, as a layer only a few inches thick, it covers a comparatively large area, and, under these conditions, is often

bleached to light ash-color and is very friable. Often it is found very solid, in unstratified deposits, the vertical thickness of which may exceed any of their other dimensions. A thickness of 100 ft. or more has been observed in the Webb City-Carterville district; in the mines around Joplin; at Galena, Kans.; and at Aurora, Mo. In such formations the shale requires heavy charges of dynamite to shatter it. Its laminations are distinct, but have no definite relations to the numerous transverse joints, which often break the shale up into rhombohedral pieces. A cross-section of one of these pieces, on the cleavage-planes, often shows within the rhomboid an oval of unaltered shale with a border of bleached shale. With this form of shale occur curiously distorted crystals of blende, from the size of a mustard-seed to that of a horse-chestnut; minute scales of white mica; crystals of dolomite; and nodules and crystals of marcasite. Numerous fragments of coal are often found with their partings of bone and thin seams of iron sulphide; as are also large bodies of what I have called "bottom-clay." Sometimes, if not always, these materials are as devoid of definite arrangement as if they had been dumped into a shaft from cars or wheelbarrows. Evidence of considerable movement throughout this heterogeneous mass is furnished by polished surfaces, dipping at all angles with the horizon, and a soft black gouge is evidently formed by the grinding together of the pieces. I have drilled through 40 ft. of this material, under more than 100 ft. of horizontal strata of alternate limestone and flint, where the upper ground was so little altered that the cuttings showed white up to the point where the shale was reached. I have also met with it at a depth of 150 ft.; but in that instance I was able to trace the crevice through which it extended almost to the surface. Similar occurrences have been reported by others. In the once rich mines on Sucker flat, I saw at the side of a shale chimney (that is to say, against a rib of solid ground) a beautiful expanse of slickensided surface, which I estimated to cover an area of 200 sq. ft. Unfortunately, the shale which formed the body of the mass, crumbled too easily to be detached from the rib. The only hand-specimen obtained, so far as I know, showed a beautiful mosaic, of ebony (shale), ivory (chert), and tortoise-shell (zinc-blende), finely polished and vertically grooved.

The "bottom-clays" are quite hard, and distinctly gritty to the touch, and show little if any cleavage. They sometimes occur in considerable masses in the body of the black shale; and they likewise contain small crystals of lead, zinc and iron sulphides. Their appearance is the same as that of the material composing the "horses" or "hog-backs" which cut through the coal-beds at Pittsburg, Kans. If fragments of coal occurred only in connection with shales and bottom-clays, they would call for little separate study, but they are also found under widely different conditions. I have myself taken out of a pocket of ochery tallow-clay about a bushel of lump coal, the lumps of which were so completely plastered with clay that it required hard scrubbing to show what they were, and expose their little-weathered surface. These lumps lay in the shaft, with as little order of arrangement as if they had been dumped from a cart into a deep mud-puddle. Perhaps the most interesting form of the shale is that which is found in connection with "spar" ground, and in dark-colored deposits of minerals, in flint ground. The miners call it "selvage," but as it occurs throughout the ore-body, and not especially against the walls, that term does not accurately describe it. It can often be traced continuously to a bed of less altered shale. The prevailing color of mineral deposits in spar ground—that is, among dolomite fragments, or against a dolomite bar—is dark; and this black "gouge" is invariably associated with such deposits. Those deposits of ore which occur in flint ground, with no limestone in evidence, and show the greatest amounts of "secondary" quartzite as cementing material, are generally dark-colored, and contain more or less of this black "gouge." On the other hand, where the ore is all free—that is, where there is no cementing material—both the blende and flint are usually light-colored. There is considerable evidence to support the view that the dolomitization of the non-magnesian limestones of these Mississippi series is extremely local; and, without doubting that silica has been dissolved out of the cherts and siliceous limestones throughout the region, I believe that the decomposition of the shale was the most probable source both of magnesia for dolomitization, and also of the soluble silica ("secondary quartzite") which is often the cementing material in the ore-bodies. I have never seen an analysis of the

shale or the bottom-clay, and I do not know how easily they are decomposed; but their close association with the most important ore-bodies so far discovered in this region makes them worthy of special study as one of its peculiar features.

These materials—the black shales, fragments of coal, bottom-clays and "gumbos"—I call the "drift" of the district. They are strangers in their present location, though they may have come only as far as from the next township. Geologically considered, their age dates from their arrival here. All clastic rocks are made up of the *débris* of older formations. This drift may have formed part of a true Carboniferous coal-measure, or even of an earlier formation; but if it was brought here in late quarternary times it is quarternary. The problem of such drift is more than a local one. It reaches to the Rocky Mountains on the one side and to the Gulf on the other. How are we to explain the occurrence of the unsorted and highly heterogeneous material which we often find in beds of great thickness? In particular, how are we to account for these lumps of very friable coal—not coal in process of formation, but completely formed coal with its "bone" and partings? Such lumps must once have formed part of a regularly deposited coal-bed, consolidated in place, under a sufficient weight of roof. It is impossible to imagine how they can have been formed otherwise. They must therefore have been eroded and transported subsequently.

The action of a river, in the formation of a delta, the erosion of banks, and the formation and shifting of bars and channel, by which it is able to shape and occupy a wide valley, is well understood. Also the terminal fans of torrential streams, and the overlapping lateral half-fans of rivers subject to great rises, are generally recognized. In these cases, the motion of the heavier material transported is a combination of rolling and sliding, and the pieces show rounded or rounding forms. But there is another motion to be considered, which I may call "crowding." Who, that has been in a painfully struggling crowd, has not noticed how the crowd melts away at its edges, and how individuals, big and little, strong and weak, young and old, emerge with surprisingly little personal damage? The strong protect the weak, the large the small; and often family parties are not separated. It is on record that, in the Johnstown flood, a pile

of china plates and a "mogul" engine were found in close proximity, and that the engine was more damaged than the dinner-plates. It can be seen annually how a great river breaks through not only artificial dikes, but also the barriers it has itself built at its normal stage. Some such "crowding" flood must have excavated and carried this drift-material.

Throughout this region, both in the ore-bearing and in the barren areas, blocks covering many square yards of ground, and 50 ft. or more in thickness, have been thrown down or up, as the case may be, and are now bounded by fractures transverse to the bedding of the rocks. These fractures answer precisely the definition of fissures, the faults produced by them have their throw and their hade, and their result, in producing dislocation of the strata, can be worked out by "fault-rules." But if they have been produced by the fall of the roof of a cavity, and are therefore limited in depth by the bottom of the cave, or if they are due to the settling of the upper rocks upon a lower stratum, the thickness of which has been reduced by the removal of a part of its material by water, we certainly cannot regard them as deep-seated fissures. In reply to a geologist, who showed me an ore-filled, faulted "fissure-vein" in the ore-body of one of Webb City's largest mines, I first pointed out how the "throw" of the fault diminished from the top to the bottom of the exposed face, and then, in a specimen of brecciated vein-filling, I traced with my finger a detached fragment of flint which would accurately fit against a larger neighboring piece if it were replaced.

The term "gash-vein," which some writers have used for deposits like these, has always seemed to me inadequate, being neither distinctive nor descriptive, and it has not met with general acceptance as the name of a class of ore-deposits. A gash is a gaping cut, presumably not deep. If it has any significance as applied to veins, it might be applied to those incomplete cuts (fissures), which are formed at the same time as a "true fissure," by a strain which is relieved as soon as the fissure is made. We often see such cracks around the funnel of caved ground. Or a "true fissure" may end in such arrested tears. Similar cracks, having no throw at their closed ends, are found alongside of fault-fissures.

I must also demur to the term "blanket-vein" as applied

to any deposit in this region. A blanket in its proper place is a component part, and forms a distinct layer in the making, of a bed. A blanket may, it is true, be much torn and bedraggled, and be trampled into the mud of a wet camping-place, and thus suggest a vivid word-picture, serving, as it doubtless has done at Leadville, to show how widely the ore-bodies there differ from the idea of the ore-veins which was in the minds of the framers of the U. S. mining laws.

The term "sheet" is, perhaps, not equally objectionable, since, in its extended meaning, it refers to the form, rather than to the position or function as a covering, and (as in the expressions, "a sheet of paper," or "sheet-metal") usually implies a limited extent.

I do not doubt that extensive and deep-reaching faults will be found throughout Southwest Missouri and the adjoining territory. Nor do I underestimate the importance of studying them, and the effect which the "litho-clases," which must have accompanied them, have had in developing the underground streams. I have studied only the shallow faults and fissures which are exposed in the mines, and by the work of the underground streams. The study of the larger, structural faults presents some difficulties, due to the prevalence of these minor faults, to local variations in composition of the rocks as originally laid down, and particularly to the weathering and cementing processes which have long been active. Mr. Wm. Wallace, in his special study of the lead-deposits of Allston Moor,[6] presents a beautiful example of what a detailed study of a complex system of faults and fissures is likely to reveal, and how far it may go towards explaining present topography, the location of the ore-bodies, and their probable origin.

I will not attempt to prove, as a general proposition, that the spaces now filled with masses of drift-material and ore-bodies are the same in form and mode of origin as those which are occupied by underground streams of the present drainage. That question must be decided for each case upon evidence taken on the ground. There are many deposits in which the evidence is not decisive either way; but if the Institute had visited Joplin in 1892, I could have taken the members to selected mines

[6] *Ore-Deposits, with Special Reference to the Lead Mines of Allston Moor.*

which in my opinion illustrated every stage of formation shown by present drainage-channels. And however much difference of opinion there might have been as to the cause, there could have been little as to the sequence of events. The paper of Mr. C. E. Siebenthal on the structural features of the Joplin district[7] is the only expert testimony I have seen which bears on the subject. His four sections on the Cornfield tract cover a length of 800 ft. on the mineral belt, which, worked at intervals, extends southeasterly from the Nevada ground, north of Webb City, to the township line, a distance of over 6 miles. I have not the slighest doubt that, if these deposits were owned by one company, they would be worked and described as a single ore-body.

In this connection I may say, that the description of the Bleyberg lead-vein, given by Phillips,[8] could be taken as a remarkably accurate description of this ore-body, if necessary changes were made as to dimensions, directions, and geological formations, together with some allowance for individual impressions in assigning causes. This similarity, however, by no means proves a similar origin. Two further factors, due to local conditions, must be considered: the effect of geological structure on the form of caves; and the effect of the strong tendency to crystallize, exhibited by the minerals of this district, upon the resultant phenomena in the Joplin region. We must at once divest ourselves of all pre-conceived notions of caves, in limestone, as arched and domed chambers, connected by passageways, and exhibiting stalactites, stalagmites, and other forms of beauty, and realize what a cave must be in a region of alternate limestone and chert. In measuring the thickness of the chert-beds, we must bear in mind that they are made up of separate layers, seldom over 8 in. thick; that these layers usually have little cohesion, the one with the other; that they are very brittle and have been severely strained, even where not broken transversely. The consequence is that, if there is a cavity below, they will "ravel out" indefinitely. To illustrate, if it be assumed that the interstitial spaces in a pile of flint blocks dropped one upon another constitute 35 per cent. of its volume, the solution of 35 per cent. of the volume of

[7] *Economic Geology*, vol. i., p. 119 (1905).

[8] *Treatise on Ore-Deposits*, p. 253 (1884).

the solid rock might extend the "cavity" indefinitely in all directions, yet keep it always filled with broken chert. The enlargement of the cavity may be at the top or bottom or at either side, wherever the material was most soluble or the water most active. As soon as the roof broke down, or the sides were sufficiently undercut, there would be vertical or lateral compression, forcing the mass into a smaller space; and this reduction of volume would be indicated by corresponding surface-depression.

The *rôle* elsewhere played by dikes and igneous intrusions in controlling and directing the flow of underground water, is here taken by bodies of shale or clay, which are less permeable than anything else found in the region, and remain so, after yielding to any stress they sustain. The miners recognize this, by calling anything which cuts out their ore a "bar." This is a confusion of ideas which makes a description of a mine very difficult. I suggested in 1887 that these shales might be the proximate source of the minerals, and thus be the equivalents of the igneous rocks, in a part sometimes assigned to the latter. It is evident that these patches of shale were once much more extensive than we find them to-day. This is, however, of minor importance. I also suggested the close of the Ice age as the time when they reached their present position. This point also is not vital, and can only be judged in the light of further studies of the physiography of this and adjoining territory.

In other mining regions, the material which goes to the dressing-works is called "ore." Here, that term is reserved, in general parlance, for the cleaned ore as it goes to the smelters. The richness of Joplin "ores" is proverbial; but it is generally overlooked that these ores are really concentrates, and that the material sent from the mines to the crusher averages less in zinc than any other zinc-ore in the country which can be profitably exploited.

This anomaly cannot be explained by superiority of methods or machinery. These, it is true, are admirably adapted to local conditions, but the local conditions themselves, involving, as they do, intermittent operations on a small scale, and frequent removal of plants (which are consequently cheap constructions), are all inconsistent with close saving or economical operation. The explanation of the surprisingly favorable

results in the Joplin district is found in the fortunate circumstance that the minerals of the ore have crystallized separately. There are lead and iron enough in all of the camps to reduce greatly the value of the zinc-ore if they could not be easily removed by jigging. I think too much attention has been given to the location of reducing agents and not enough to the force which determines crystallization, in producing workable ore-deposits at any particular *locus*.

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* SECRETARY'S NOTE.—The Council is the professional body, having charge of the election of members, the holding of meetings (except business meetings), and the publication of papers, proceedings, etc. The Board of Directors is the body legally responsible for the business management of the Corporation, and is therefore, for convenience, composed of members residing in New York.

BI-MONTHLY BULLETIN.

For the convenience of persons who desire to file, or otherwise use separately, the technical papers in Section II. of the Bulletin, each of these papers has been paged and wired by itself; the whole collection being held together by a single, heavy wire, upon the removal of which it will fall apart into individual pamphlets, substantially like those formerly issued.

A small stock of separate pamphlets, duplicating the technical papers given in Section II. of this Bulletin, is reserved for those who desire extra copies of any single paper.

All communications concerning the contents of this Bulletin should be addressed to Dr. Joseph Struthers, Assistant Secretary and Editor, 29 W. 39th St., New York City (Telephone number 4600 Bryant).

UNITED ENGINEERING SOCIETY BUILDING.

The following description of the United Engineering Society Building, No. 29 West 39th Street, New York City, was prepared for the Dedication Exercises, April 16–19, 1907, by the historical and publication press committee, Mr. T. C. Martin (*Chairman*), Mr. Albert Spies and Mr. H. H. Suplee.

Historical.—During the past twenty years, the project has been frequently discussed and agitated of bringing together in one building, with proper facilities for offices, library, auditorium, meeting-rooms, etc., the various engineering societies that make their headquarters in New York City. References to the idea may be found in various transactions and technical journals as far back as the early eighties, for even then the desirability of such accommodation had already become a topic of conversation among engineers. As a matter of fact, however, the process of society formation was then still quite active, and the tendencies were centrifugal; although with the creation of each new body the difficulties as to headquarters increased very rapidly. The societies, old and new, all grew apace, acquired valuable property in books, furniture, relics, etc., but, in general, had to content themselves with rental of small private houses or rooms therein, subject to loss by fire and to other grave inconveniences.

In 1895, an actual plan for such a joint home was submitted to Mr. Andrew Carnegie by Mr. W. D. Weaver, a member of the American Institute of Electrial Engineers, who received a reply of warm approval and commendation. Others are understood to have made suggestions later of the same nature. In February, 1903, Mr. Carnegie, as one of the contributors to the library fund of that Institute, was invited to attend its Library Dinner, and after four declinations on account of inability to arrange a date, accepted. The dinner was given on February 9, at Sherry's, when Mr. Carnegie spoke on co-operation among engineers. The President of the Institute told of its growth

and the need of a building for engineering societies. The next day Mr. Carnegie sent for Mr. C. F. Scott, President of the Institute, and Mr. Calvin W. Rice, chairman of its Building Committee, and discussed with them broadly the idea of a union engineering building. He said that a scheme of that kind should embrace the social as well as the technical interests of engineering. His attention was called to the fact that the Engineers' Club had just secured land for a new house in West Fortieth street, opposite the new Public Library. The locality appealed to Mr. Carnegie as highly suitable, and on February 14, after conferences in which Messrs. John Fritz, J. C. Kafer, John Thomson and W. A. Redding joined, he wrote a brief letter, saying:

"It will give me great pleasure to give, say, $1,000,000 to erect a suitable union building for you all, as the same may be needed."

This splendid donation to engineering was followed by a prolonged series of negotiations with respect to participation in it by different bodies, and by formative work and discussions in which a number of engineers of prominence took part in aid of the enterprise. About one year later, March 14, when the plans and estimates showed that a larger sum would probably be required to carry out the work on an adequate basis, for engineering societies in general, Mr. Carnegie in a further letter, addressed to the American Institute of Electrical Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, and the Engineers' Club, increased this sum to $1,500,000 in their joint behalf.

The only limitation on the gift was that it should be devoted to the erection of a building, the bodies interested buying the land. At the outset it was proposed to put up one building on Fortieth street, but owing to the difficulties involved in the purchase of as much land as would be necessary and in combining under the one roof all the social and technical functions exercised by these organizations, it was decided to erect two separate buildings, one for the Club on Fortieth street and one for the professional societies on Thirty-ninth street, the two buildings to be placed in such relationship and contiguity that access from one to the other would be easy and the underlying common purpose thus be subserved to the full extent.

Each of the bodies named in the letter appointed three of its members to form a joint Conference Committee of twelve, whose duty it should be to accept the gift and erect the buildings, and that Committee has remained in active existence up to the moment of the dedication of the Engineering Society Building. It comprised the following: *American Society of Mechanical Engineers*, C. W. Hunt, J. M. Dodge, F. R. Hutton; *American Institute of Mining Engineers*, A. R. Ledoux, C. Kirchhoff, T. Dwight; *American Institute of Electrical Engineers*, C. F. Scott, C. W. Rice, T. C. Martin; *Engineers' Club*, W. H. Fletcher, J. C. Kafer, W. A. Redding. In organizing for its work this body made Mr. Scott chairman, Prof. Hutton secretary, and Mr. Kafer treasurer. Various changes occurred in the personnel of the Committee from time to time. Dr. Ledoux was succeeded by Mr. E. E. Olcott. Messrs. Rice and Martin were succeeded by Dr. S. S. Wheeler and Mr. Bion J. Arnold; and later Dr. Wheeler gave place to Mr. John W. Lieb, Jr. Mr. Martin succeeded Mr. Redding; while Mr. Kafer, on his death in 1906, was succeeded by Mr. George E. Weed, and Mr. Kirchhoff became treasurer. One of the most important duties of the Committee was the division of the gift in proportion to the requirements and object of the two buildings. The delicate task was accomplished by allotting $1,050,000 to the Engineering Societies Building, and $450,000 to the Club Building, by unanimous vote. It will readily be understood that while the nine representatives of the technical bodies and the three of the Club devoted attention to their specific buildings throughout the three years of constructive work, there were a great many questions that required the constant consideration of the Conference Committee as a whole.

The Site.—The site acquired for the Engineering Societies Building is on West Thirty-ninth street, north side, between Fifth and Sixth avenues. The frontage covers five city lots, Nos. 25 to 33, the total front being 125 ft. This land has been bought with money advanced by Mr. Carnegie through Mr. R. A. Franks to the three engineering societies at 4 per cent. interest, the cost being $540,000, one-third of the amount being payable by each society. To the east of the property, light and air for the building are satisfactorily insured by the purchase by the Club, for its own protection, of a large four-story

private house of "restricted" height; the Club-house being in the immediate rear of the Engineering Building.

Selection of Architect.—The Conference Committee spent its first year in disposing of the various questions arising in the acquisition of real estate, deciding upon the method of holding title to the property, making arrangements for the administrative details, and determining as nearly as possible the actual requirements of the proposed building. It then became necessary to select an architect. The world-wide fame of the donor, the magnitude of his gift, the national character of the engineering societies, and the great cost of the contemplated edifice, made the selection of an architect a semi-public matter of more than ordinary importance.

The plan of selection adopted was that of a "mixed competition," in accordance with what was understood to be the wish of Mr. Carnegie. In carrying out this plan, six architects of high reputation were invited to participate. Each of the invited architects was to be paid $1,000 for submitting his plan, whether it was accepted or not. In addition, other architects were invited to present plans, but without compensation, and the competition was also thrown open to all architects who for two or more years had been in the actual practice of their profession, under their own names. Four prizes of $400 each were provided for the best designs of the non-invited architects in the "open" class. All plans were submitted anonymously, and the Committee associated with itself as professional adviser Dr. W. R. Ware, Professor Emeritus of Architecture in Columbia University.

In July, 1904, the Committee made a careful examination of the plans thus submitted, at the rooms of the American Art League, New York City; 26 sets of plans, comprising over 500 drawings, having been received for the two buildings. The programme called for a handsome but not too ornate treatment of the Engineering Society Building, the side and rear walls to be reasonably conformable in architectural treatment with the front elevation, so that the edifice might have the aspect and character of a completed structure rather than that of a section of an unfinished block. All drawings were in india ink, on plain white paper without color, to a scale of $\frac{1}{16}$ in. to a foot, accompanied by a sealed envelope giving the name of

the architect and by a general specification as to the plans. After a very careful study of the numbered sets of plans, it was found that the unanimous choice of the Committee, with the warm approval of the professional adviser, had gone to Messrs. Herbert D. Hale, of Boston, and Henry G. Morse, of New York, associate; who were forthwith appointed the architects for the building and who, as the firm of Hale & Rogers, and H. G. Morse, associate, carried out the work. The award for the Club-house was similarly made by the Conference Committee to Messrs. Whitfield & King, of New York.

The Holding Corporation.—It was found necessary to organize a holding corporation to administer the endowment and property for the three Founder Societies jointly and in common; and the novel conditions attending the acceptance and utilization of the gift raised many legal and economic problems as to the mutual relationships, duties and rights of the recipients. A corporation was formed by special charter in the State of New York, in May, 1904, called the United Engineering Society, to act as the trustee for the three Founder Societies, and its nine trustees are chosen periodically three each by the Councils of the Electrical, Mechanical and Mining Engineers, to control the building and regulate its finances. The title of the land rests also in this body corporate. The character of the Society, its by-laws, etc., were given most careful thought by the Societies, their legal counsel, the Committee as a whole, and in particular by Dr. S. S. Wheeler, to whom the intricate matter was intrusted as chairman of a sub-committee. The first President of the United Engineering Society was Dr. A. R. Ledoux, who was succeeded by the present incumbent of the office, Mr. E. E. Olcott. The Society took title to the land on which the building stands in January, 1905. It may be stated that while the charter and by-laws of the Society have been framed to protect the interests of the three "Founder Societies," under the gift, careful provision is made also for the welfare of the "Associate Societies"—*i. e.*, the numerous other technical bodies occupying the building as their headquarters.

General Data.—The contract for the construction of the building was executed with Wells Brothers Company on July 17, 1905. The cornerstone of the building was laid in the eastern wall by Mrs. Andrew Carnegie on May 8, 1906. The time of

completion was fixed for Nov. 15, 1906. Offices were ready for occupancy on Dec. 15, 1906; some were in use before the end of the year, and the entire building, though not quite finished, was ready for use Jan. 1, 1907. This remarkable expedition was largely due to the fact that at no time did the architectural plans require important revision. A steel strike in the spring of 1906 lasted one month and a plaster strike in November about two weeks, but the building was erected within the specified time and within the appropriated sum, and the relations of the Conference Committee, the architects and the general contractor have been throughout of a most harmonious nature.

The Building.—The frontage of the Engineering Society Building on West Thirty-ninth street is 115 ft., and the depth is 90 ft. The property itself is 125 ft. front by 100 ft. depth. The building laws of the City of New York require that only 85 per cent. of the lot area shall be occupied by the structure on it. Advantage has been taken of this limitation to give the building a monumental appearance. It is designed in the latest French Renaissance style and rises 13½ stories above the sidewalk to a height of 218 ft. 6.5 in. The exterior is built of limestone up to the Auditorium floor, and of gray mottled brick and terra cotta above; the whole having a cheerful cream tint on all four sides. The treatment is restrained and dignified, but without severity. As the lower portion is devoted to auditoriums, the middle section to offices, and the upper part to the library, an effort has been made to accentuate these three separate parts of the building, with a happy result, as shown by the frontispiece engraving.

In excavating for the foundations, rock was found at from 27 to 67 ft. below the curb line, and there are 46 concrete piers in the foundation going down to solid rock. Two of these piers sustain a load of 3,000,000 lb. each in weight of structure alone, and the steel columns at these two points weigh 1,000 lb. to the vertical foot. The steel plate-girders in the ceiling of the Main Auditorium weigh 48 tons each, and the steel lattice-truss on the sixth floor weighs 64 tons. The total weight of steel employed in building construction is 2,650 tons.

All the steel-work in the building has been covered with from 2 to 4 in. of semi-porous terra cotta, and the columns are

grouted with concrete. The floors are built with terra cotta 6-in. segmental-arch construction, overlaid with 5-in. of cinder concrete. All exterior walls are furred with 2-in. terra cotta blocks, to prevent any possibility of moisture being driven through the walls.

Access to the building is gained by the central entrance on the street level to the first floor; by the western side door leading to the elevators; and by the broad driveway which encircles it completely, so that carriages can enter by the eastern covered arch, set down their occupants at a side entrance and emerge by the western gate. There are three elevator riseways in the main elevator-shaft, faced with an iron grille lined with wire-glass. On each side of this shaft wide stairways rise to the sixth floor of the building, and one leads thence to the Library floor. A freight-elevator has been installed on the eastern side of the building, and a commodious service stairway on the north side rises the entire height of the edifice. At the first floor, a rear door communicates across the 10-ft. areaway, in the open, with the café of the Club-house, and on the ninth floor, a flying covered bridge connects with the breakfast-room on the tenth floor of the Club.

The wood-work in the building has been reduced to a minimum. The large windows are built of cast-iron, and the other windows of wood covered with kalamined-iron, such windows having only a small molding in place of the usual wide trim and casing. All the doors in the basement, first floor and at the ends of the Auditorium promenade are kalamined-iron fire-doors, and the exit door to the Engineers' Club is built of electroplated copper on wood. All the wood-work, including floors, sleepers, trim, etc., has been fire-proofed. The windows up to the height of 100 ft. are glazed with wire-glass, except on the Thirty-ninth street front, thus bringing the exterior fire hazard down to the lowest possible point. All finished floors throughout the building are of cement, marble or terrazzo, except in the Library, Main Auditorium and lecture-rooms, where maple has been used. The insurance rate of 15 cents for this building is the best proof of its safe construction and solid workmanship. Moreover, additional precaution against fire has been taken by placing an 8,000-gal. tank on the roof, with a stand-pipe at each end of the building, the tank being fed by two electric pumps.

All the walls and ceilings are painted in neutral tints, and the decoration is simple though carefully studied, especially with an idea to later development in the way of mural paintings, the setting of the names of distinguished engineers in plaques, niches for bronze or marble busts, panels for bronze tablets, etc. Opposite the elevator-shaft on each of the three Founder Societies floors, the emblem of the society occupying the floor is reproduced in a heavy brass plate set into the terrazzo floor. The hardware throughout is in a subdued brass finish, is quite massive and is master-keyed for all doors. The mail-chute is ornamental and of the latest pattern. The driveway is defended by handsome wrought-iron gates specially designed, and over the main entrance a large bronze plaque has been set, bearing the words, "Engineering Societies," to explain the purpose of the building to passers-by.

Basement and Boiler-Room.—The basement is occupied in part by the boiler-room, 22 ft. below the curb, and the engine-room, 16 ft. There is also ample coal-storage on the north side, and storage facilities for the various societies, chiefly owing to the fact that it was decided inadvisable to install an isolated light- and power-plant. All electrical energy is taken from the mains of the New York Edison Co. The entire basement and boiler-room up to the level of the curb have been made thoroughly water-proof, and a sump pit has been installed to avoid any danger from extreme pressure. An ash-hoist empties into the driveway.

Steam is employed for heating and ventilating purposes, generated at low pressure by three boilers of the wrought-steel header type, of Babcock & Wilcox manufacture, having an aggregate of 5,226 sq. ft. of heating surface. The boilers, as well as the valves, piping and attachments in connection with the boiler-plant, are designed and arranged for high-pressure steam, should it at a later date be desired to install an electric generating plant.

Method of Heating.—The heating of the building is accomplished by low-pressure steam circulating through radiators placed underneath the windows. This not only represents the most economical method of heating, but it is the most effective means of counteracting the down-draft from the windows. The radiators in the entire building are controlled automatically by

the Johnson system of heat-regulation, so that the rooms will be maintained at a uniform temperature without hand-control, irrespective of outside conditions of wind and weather. No blowers or mechanical means are required for heating the rooms. The extensive blower-system installed is for ventilation solely. The ventilation is independent of the heating-system, for while in the winter months the building must be heated 24 hours per day, the ventilating-system is required only when the halls and rooms are occupied. This separation of heating- and ventilating-apparatus is, therefore, fraught with economy and simplicity of operation. The Paul vacuum system of steam-circulation is utilized in connection with the direct heating, with the tempering-coils and with the air-moistening apparatus.

Ventilating Plant.—A thoroughly modern and effective ventilating-apparatus is provided for the lower six floors, which contain the large assembly-rooms. Pure, fresh air in large quantities is supplied to all the rooms and the main corridors in the lower six floors by means of four electric-driven Sturtevant blowers located in the basement. Air is exhausted from these floors and from the basement, as well as from the toilet-rooms throughout the building, by means of four electric-driven Blackman exhaust-fans located in fan-houses on the roof. C. & C. electric motors are installed for driving the blowers and exhaust-fans.

One hundred thousand cubic feet of fresh air per minute represents the air-supply, when the blowers are all operated at one time. The fresh air after it has passed through the air-inlet to the large chamber in the basement, is drawn through the air-filters, which free it from dust and the finer mechanical impurities. After the air has been filtered it passes over tempering-coils and moistening-pans, and is warmed and moistened in the winter months. It goes thence through the blowers, and, by means of the galvanized-iron duct-system located in the basement, to the vertical flues, entering the rooms through registers in the walls and ceilings.

The quantity of air supplied to the individual rooms varies, of course, with the special uses, but in every case a sufficiently large air-supply is secured to keep the air pure. Special and unique features were adopted in the building construction so as to introduce the air into and exhaust it from the rooms by a

great number of registers, so that a large volume is introduced at a low velocity, and thus a perfect air-distribution is secured. The heating- and ventilating-plant was installed from the plans and specifications and under the supervision of Mr. Alfred R. Wolff, consulting engineer. It should be noted also that the plans of the halls were submitted to and approved by Prof. W. C. Sabine, of Harvard University, as expert on the acoustics of public halls.

The plumbing has all been installed upon the most modern principles of sanitation. All toilet-rooms are in marble, and substantial wash-bowls are installed in the office-rooms. The fixtures are of the best and simplest type. All the water is filtered.

The Electrical System.—As in the case of the other departments of the building, the electrical equipment and the illumination had to fulfill unusual and peculiar requirements, owing to the special purpose for which the building is to be used. In the following brief description, therefore, the usual features of illumination and of the electrical equipment need but be mentioned, while the unusual and somewhat novel features will be more fully described.

The electrical current supply for the building is derived from an outside street-main service introduced into the building from the New York Edison Co. and the United Electric Light & Power Co., so that both alternating and direct currents are available.

The feeders and mains for the lighting-system are arranged on the three-wire system, and on the two-wire system for power. In all cases, all of the wires of a given circuit are installed in the same conduit, so as to permit alternating current to be used on any circuit in the building.

As the building is to be used by different societies, it was essential that the feeder-system should be arranged so as to provide means for measuring the current-consumption separately in different portions of the building. For this reason, the feeders were sub-divided and the switchboard designed to have meters on each feeder, so as to permit making proper charges for electric current for each floor; separate feeders, of course, being provided for the entrance-halls and corridors.

Two separate feeders from the New York Edison Co. have

been introduced into the building, so as to afford additional security in case of failure of one of the service mains. Two separate feeders are provided for the lighting of the Main Auditorium, connecting at the switchboard with the two independent service street feeders, thereby providing duplicate and independent lighting-service for the Main Auditorium, so as to preclude, as far as possible, the liability of interruption of the lighting-service of the Auditorium. By means of the two hall feeders, it is possible to light one-third, two-thirds or all of the hall and corridor lights from the switchboard in the basement.

A control switchboard has been provided for the Auditorium, in the passageway back of the stage. At this point, the feeders terminate and all of the circuits for the Auditorium originate and are controlled. At the upper part of the switchboard, dimmers are provided for the control of the Auditorium lighting. At this point also, the special feeders and empty conduits for demonstration purposes terminate. Special outlets have been provided on the stage for musicians' lamps, table-lamps, etc. Stage-pockets are located in the center of the balcony and in the floor of the center aisle of the main floor, for stereopticon or similar purposes.

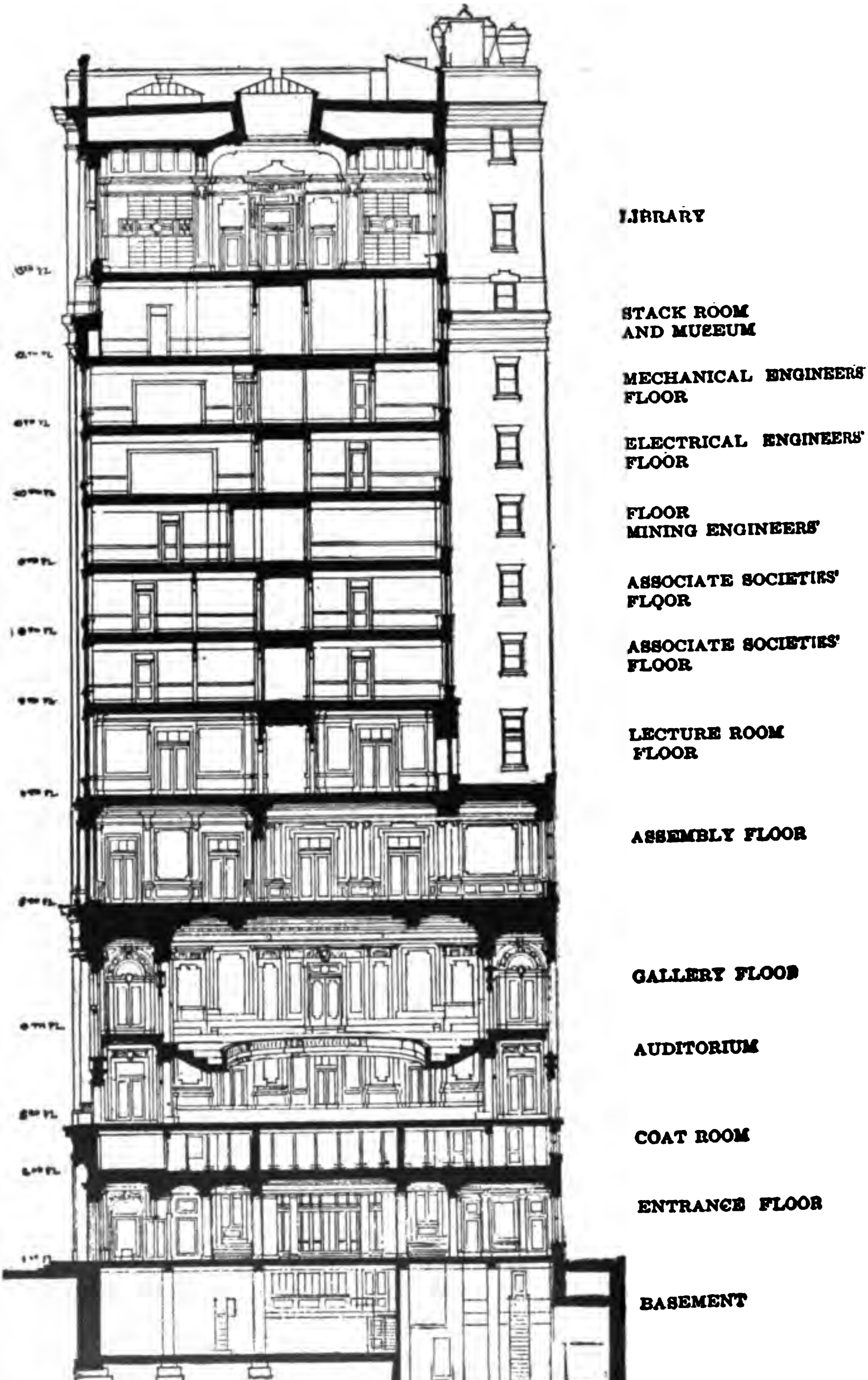
Cut-out panels have been provided in each of the assembly- and lecture-rooms at fifth and sixth floors, so as to provide convenient control of the lights in each room. Special feeders and empty conduits have been provided for demonstration purposes in all of these rooms. Special outlets have been provided in the Library for lights on desks, tables, etc., and special circuit-work has been done for stack-lighting for present and future use. In each office a circuit is run to a corner in the ceiling in each room, and from this point a square of molding is placed 18 in. from the wall and symmetrically aligning with the room parallelogram. At any point on this molding a small rosette may be inserted and an attachment for a drop-light provided.

In order to provide ample current-facilities for demonstration purposes, lectures, etc., special feeders have been run from the switchboard in the basement to the Auditorium, and to each of the assembly- and lecture-rooms. The connections of these feeders at the main switchboard in the basement are such that any desired arrangement or combination of the conductors may be made, and, if desired, connections for either direct current

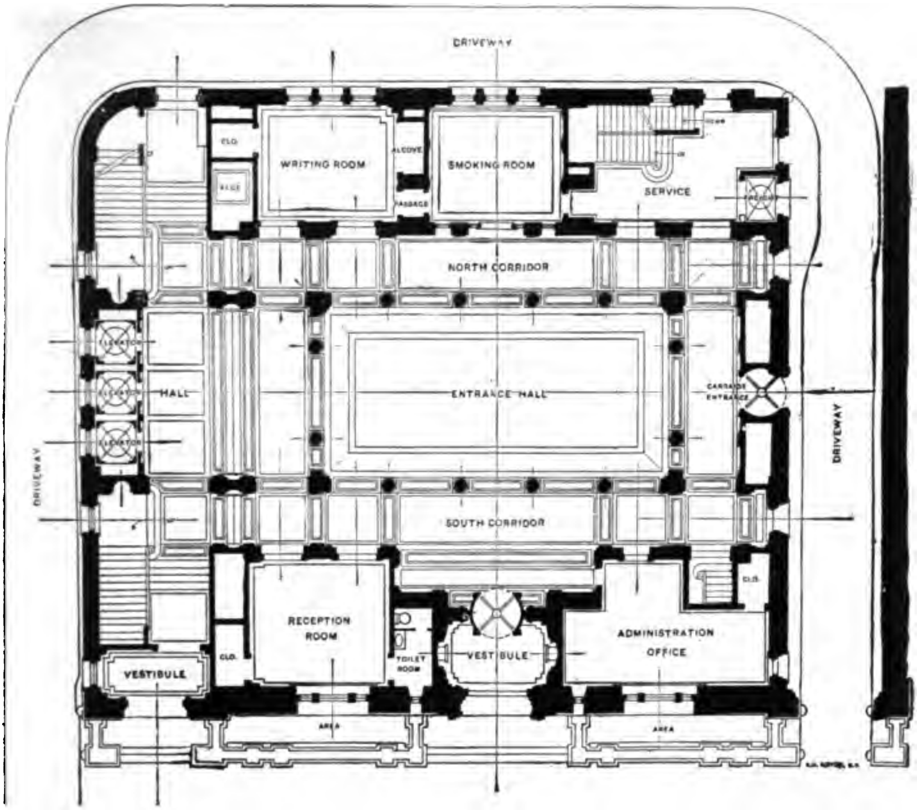
Engineering Society Building, from West Thirty-ninth Street.

Main Entrance to the Building.

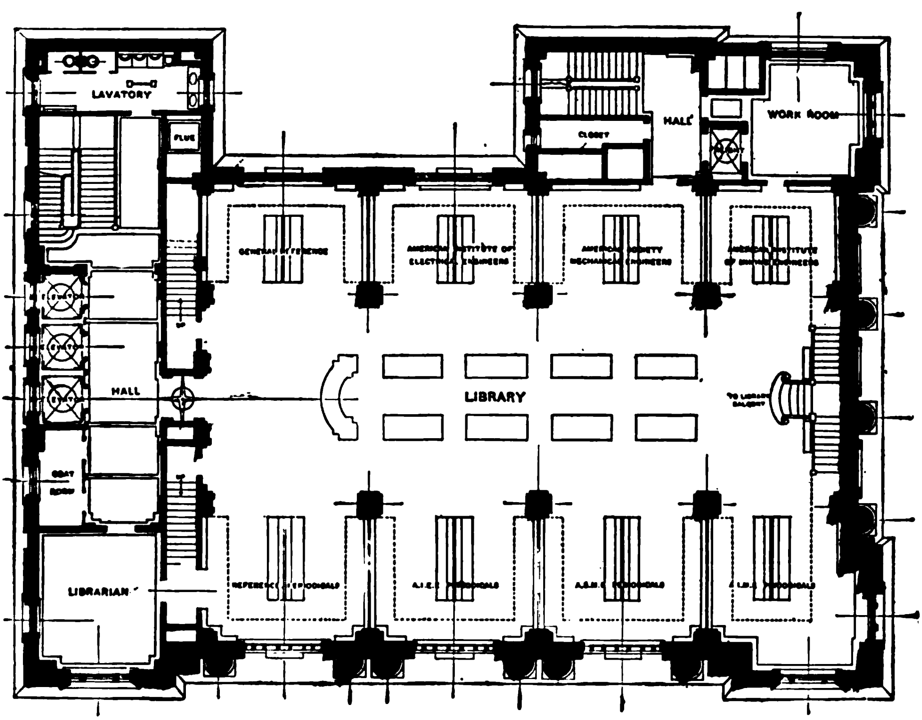
Lower Facade of Engineering Society Building.



SECTIONAL ELEVATION OF BUILDING.



Plan of Foyer and Entrance.



Plan of Library Floor.

The Main Auditorium, Looking from Speaker's Desk on Platform.

View of Library, Looking Toward Entrance.

Main Auditorium, Showing Platform.

or alternating current, single phase, two-phase, three-phase, may be quickly and conveniently made.

In addition to the special feeders, empty conduits are run to the Auditorium and lecture- and assembly-rooms, so as to afford raceways for any purpose for which the special feeders would not provide. In the case of the Auditorium, two 3-in. conduits run to and terminate in a cabinet at the back of the stage. In the case of the assembly- and lecture-rooms, a single conduit of 2.5 in. internal diameter has been provided.

A complete and flexible interconnection system has been provided for the building, having its main center in the basement. It affords means for connecting telephones or call-circuits in practically every office in the building. In order to avoid running wires around the picture-molding or along the baseboard in the offices, a system was devised by the electrical engineers of having a portion of the base removable, with ample space in the form of a channel extending completely around the room. In order to make this channel continuous, conduits are run under the doors, connecting with the channel space at either side of the door. This channel is connected by means of a conduit with the nearest interconnection-box on the floor.

The Illumination.—Complete specifications were prepared and sketches made by the consulting engineers, acting in co-operation with the architect, for the illumination of every room, and for every fixture in the building. It was realized by the engineers that the illumination was necessarily only one feature of the building and must be subordinate to, and in harmony with, the architectural features.

The central space in the entrance-hall or foyer is lighted by means of individual lamps, placed in recesses, and concealed by panes of ground-glass in the ceiling, at the sides of the rectangle formed by the columns around the large central area. In addition to this, larger crystal balls are provided in the outer corridor beyond the central space and in the elevator-hall, entrances, etc. The effect of the individual lights in the recess, screened by glass, is to afford ample illumination without any glare. Crystal glass balls, holding "metalized filament" lamps of various sizes from 50 to 250 watts, are used on the principal floors, from the first to the fourth, inclusive.

In the halls above the fourth floor, glass globes have been

provided to screen the lamps. These globes, made according to the specifications of the electrical engineers, are unusual in the fact that the brilliancy of the lamps is reduced without an excessive loss in the efficiency, and at the same time, a warm, pleasing opal glow is produced.

The lighting of the Auditorium is the most effective and probably the most interesting feature of illumination in the building. The result was obtained by the complete co-operation of the electrical engineers with the architects. At the engineers' suggestion, the architects provided a space of about 15 in. between the ceiling of the Auditorium and the beams of the floor above. At the suggestion of the engineers, also, a glass septum was substituted in place of the proposed plaster panels in the ceiling. The details were then carefully worked out for obtaining access to the lamps for renewal, and tests were made by the engineers to find a glass that would reduce the intrinsic brilliancy or glare, and at the same time would not have an amount of absorption prohibitive on the score of economy. The result obtained is very satisfactory. The general effect is both soft and pleasing, and resembles or suggests sunlight passing through glass, as at Napoleon's Tomb in the Invalides, in Paris. As a matter of fact, the solid arches of the floor above are within 2 or 3 ft. of the glass through which the light passes. Additional lighting screened by the same kind of glass is provided at the rear and at the sides under the balcony. Dimmers are provided for reducing the amount of illumination in the Auditorium to any desired point, and also for the purpose of gradually increasing the lights to the maximum, after the room has been darkened for a stereopticon, thereby avoiding the unpleasant sensation produced on the retina of the eye, by flooding the room with light immediately following comparative darkness.

The lighting of the assembly- and lecture-rooms was also designed to prevent the lights from being distracting or unduly noticeable. For this reason, the cove method was adopted, with additional outlets in the ceiling for supplemental fixture lighting. The difficulties of the building construction did not admit, in all cases, of obtaining continuous coves, or coves of the exact form and dimensions desired. While the cost of lighting by this method is in excess of that of using ex-

posed lamps, the fact that the rooms are not in continuous use, but occasionally, for lecture purposes, offsets this objection.

The general illumination of the Library is obtained by means of lamps placed above the glass ceiling skylight on a plan similar to that used in the Auditorium, the glass used being of the same kind as that in the Auditorium ceiling. In addition, ceiling outlets are provided for general illumination, so that the indirect lighting above the glass need be used only at certain times. The light for reading is obtained by means of standard fixtures placed upon the tables. The general effect is charming and agreeable.

The specifications and plans for the electrical equipment, the illumination, electric fixtures, etc., were prepared by Messrs. C. O. Mailloux and C. E. Knox.

The Electrical Energy Supply.—As noted above, the supply of electrical energy to the building is furnished from outside and not from an isolated plant. The New York Edison Co. reaches the building by means of two 1,000,000 circ. mil cables; one being a bifurcation of its feeder from East Thirty-ninth street to Thirty-eighth street and Fifth avenue; and the other being a direct feeder from the West Thirty-ninth street station, near Broadway. There is a 500,000 circ. mil service from the main on the north side of the street and a 350,000 circ. mil service from the main on the south side of the street. In addition there is a United Electric Light & Power Co.'s service for 60-cycle alternating current.

At the switchboard the installation of the building is divided into two parts. One feeder and one service from a main supplies one part, and the other feeder and the service from the other main supplies the second part. Either pair of services is sufficient to take care of the whole building. Double-throw switches are arranged so that ordinarily half of the installation is supplied from each pair of services; but in case of interruption on either pair, the double-throw switch may be thrown so that the full load of the building can be supplied from the other one.

The Electric Elevators.—The elevator-shaft for passenger-travel occupies the middle part of the western wall of the building. There are two Otis passenger-elevators, 3,100 lb. maximum load, speed 325 ft. per min. with 2,500 lb. load. One

elevator travels from the basement gallery to the thirteenth floor, about 207 ft., and one from the first to the thirteenth floor, about 196 ft. These are of the latest type, electric drum machines, being equipped with double screws, compound momentum-brakes, automatic stop-motion switches mounted on the drum-shafts for limiting the car-travel at either end, hoistway-limit switches, slack-cable switches and emergency brakes.

The cars are of approximately 33 sq. ft. area and are carried in steel slings or girdles which are fitted with the improved wedge-clamp safety device which operates in connection with an Otis governor. This safety device is so constructed as to be made to grip the guides if a car is descending at undue speed. Each car is counterbalanced with very nearly its own weight, and to the back of each drum is attached a separate weight equal to the average load carried in the car. This arrangement of counterbalance gives the most economical results in current-consumption.

The elevators are equipped with six $\frac{3}{4}$-in. standard iron hoisting-cables, each; two being for lifting, two for car-counterbalance and two for back-drum counterbalance. The weight of these cables is compensated by chains attached to the bottom of each car sling and anchored midway up the shaft. In addition to the wedge safeties above referred to, these elevators are equipped with the security retarding safety, which acts in dependently of the other safeties.

The elevators are controlled by means of hand-operating switches conveniently located in the cars, and, in case of accident, the current-supply to the machine and operating-switch can be entirely cut off by the operator, and the emergency brake applied by opening a small switch, known as the safety switch, which is located near the car operating-switch above referred to.

The freight-elevator, which travels from the basement to the fourteenth floor at the rear of the building, has a car-area of about 24 sq. ft. and a maximum lifting-capacity of 3,000 lb.; speed with a load of 2,500 lb. is 250 ft. per min. This machine which is also a lifter of safes, is provided with a back-gear attachment that can be readily connected or disconnected by the engineer, by means of which the machine can be made to lift 5,000 lb. at a low rate of speed.

A locking device is also provided for holding the car securely at any floor-level while loading or unloading. In all other respects this elevator is similar to the passenger-elevators. The plant is operated on the 110-volt direct-current circuit.

The Telephone Equipment.—Realizing that in a building of this nature the most up-to-date engineering ideas would be embodied in every feature of construction and administration, a careful study was made of the needs of the Founder Societies and the other tenants in the building with respect to the telephone service, in order that the plant might be adequate and the telephone service thoroughly efficient. Such a study indicated that the most convenient and flexible, as well as the most economical service could be effected by arranging for one switchboard for the entire service throughout the building, from which all of the trunk lines to the central office of the telephone company should extend, and in which all the extension telephones in the building should terminate.

Accordingly, a specially designed single-position switchboard to include all the most modern features, and finished to harmonize with the architecture of the building, has been installed. The switchboard has a capacity of 15 central-office lines and 60 extension telephones. This gives the building a flexible telephone service, since from any telephone at any point in the building communication may be had with any other telephone in the building or with any local, suburban or long-distance point through the lines of the New York Telephone Co. and its sister telephone companies.

Telephones have been installed in the offices of the three Founder Societies, and, in addition, in the engine-room, service-halls, coat-rooms, Library, the stack-rooms, at the demonstrating-tables, to be used by the lecturers, in the janitor's quarters, and at all points of activity, in order that it may be possible to send or receive telephone messages at any point in the building.

It is estimated that about 12,000 messages per year will be originated from the telephones in this building, and the contract to cover this number of messages has been arranged for. In addition to the telephones throughout the building, three booths have been installed on the ground floor in order that visitors to the building or tenants may send messages from this point.

First Floor.—The spacious first floor is laid with Tennessee marble tile, having a border in design of colored marble. The central court or main foyer is marked by twelve large columns of Swiss Cipolin marble. A short low flight of steps leads from the foyer to the elevators, and at will a metal grille is thrown across the steps so as to restrict or direct travel. Gold ornament is used sparingly for architectural accentuation, and the wood-work is in dark oak. Large chairs and lounges in red leather furnish the foyer, and similar furniture is used in the writing-room, smoking-room, reception-room and administration-room, which also contains three telephone booths associated with the "private exchange" system. On the foyer walls, facing toward the main entrance, are two large bronze tablets, one bearing a relief portrait of Mr. Carnegie and the words of his terse letter of gift of $1,500,000, and the other a statement to the effect that the land was given by members and friends of the three Founder Societies. On this floor also, at the rear, are the receiving- and shipping-offices through which all freight and goods are handled. In time this floor will be graced with statuary, but even now it creates a most favorable impression as one enters the building.

The Main Auditorium.—Immediately above the first floor is the coat-room, laid out on a sectional plan so that several lines of persons may be accommodated at once on entering or leaving. This half-floor virtually occupies the space that would otherwise be left blank by the slope of the Main Auditorium floor just above it.

The Main Auditorium extends up through two floors and with its gallery will seat about 900 persons. The requirements of this chamber were unusual and difficult of definition. It had to be arranged primarily for the general meeting of the Societies, at which the speaking is from the floor as well as from the platform, and at which diagrams, illustrations or blackboard drawings are often employed. This is quite the opposite from the ordinary audience-hall, where the stage is the starting-point both for the seating-arrangements and for the acoustic and optical necessities. Hence the platform is notably small for so large a hall, accommodating few persons, while any speaker in the audience is easily within range of observation.

On both the parterre and the gallery floor, at the sides, the Auditorium is surrounded by corridors, rendering access to every point very easy, and permitting ready withdrawal for conversation, committees, etc. The corridors assist also in maintaining quiet within the hall. The platform has ante-rooms and is conveniently close to the freight-elevator, for the delivery of apparatus. There is also a fine stereopticon equipped with connections for moving pictures. The seats are fixed opera-chairs in red leather with revolvable tops, and the aisles are laid with red carpet. The gallery-front is bordered in red plush. Above the Auditorium arch is a decorative cartouche bearing the badges of the three Founder Societies. There are side brackets for lighting, but the main illumination is effected indirectly through the glass ceiling, above which are incandescent lamps controlled from several panel-boards. The elevators and stairs open directly upon the two floors of the Auditorium, which can thus be emptied very quickly in case of emergency. Practical tests of the chamber have already shown it to be a success in every respect of comfort and convenience.

The Lecture-Rooms.—The next two floors above the Main Auditorium are devoted entirely to lecture-rooms, of which there are no fewer than seven. Two spacious assembly-rooms, 51 ft. by 66 ft. and 29 ft. by 66 ft., occupy the larger part of the fifth floor in such a manner that they can be used independently, or one may be made auxiliary to the other. Two smaller rooms on this floor, 16 ft. by 22 ft. and 18 ft by 19 ft., can be also used separately or as annexes for reception or conversazione purposes, and provision is made with steam-tables, etc., for the service necessary for luncheons or light refreshments. All these rooms are agreeably finished in soft light tints and have facilities for water, air, electric connections, etc., for demonstrations and experiments.

The sixth floor is also divided into lecture-rooms, planned somewhat differently, and of smaller dimensions than those on the floor below. The dimensions are respectively 22 ft. by 44 ft. 6 in.; 30 ft. by 46 ft. 6 in.; 30 ft. by 41 ft., and 20 ft. by 28 ft. In this manner the building affords facilities to audiences of every size from 1,000 down to 100; while on occasion every room can be occupied by sections and sub-divisions of an en-

gineering or scientific congress with independence and without interference.

The Office Floors.—The seventh and eighth floors of the building have been reserved for the Associate Societies that have engineering or some department of science as their principal object. For these organizations the building affords office areas of varying size, from one room up, with the common facilities of the lecture-rooms, library, and other accessories. Among these societies may be enumerated the Society of Naval Architects and Marine Engineers, the Society of Heating and Ventilating Engineers, the National Electric Light Association, the Society of Chemical Engineers, the New York Electrical Society, the Association of Edison Illuminating Companies, the American Street and Interurban Railway Association, etc.

Founder Societies Floors.—Each of the three Founder Societies occupies a floor laid out in accordance with its own plans. The American Institute of Mining Engineers has the ninth floor, the American Institute of Electrical Engineers has the tenth floor, and the American Society of Mechanical Engineers has the eleventh floor. These floors are all devoted to administrative and executive work, and the libraries of the three societies have been concentrated in the two top floors of the building.

The Library.—A crowning detail in the plan of the building has been the reservation of the twelfth and thirteenth floors for the libraries of the three Founder Societies and of such other collections of engineering literature as may be added. The twelfth floor, below the Library proper, has been devoted to the book-stacks, but at the present time the main Library is also equipped with one tier of stacks, with provision for a gallery tier later. The stack-room is partly equipped with stacks, and in the Library a delivery-desk, reading-tables and chairs have been provided. The Founder Societies entertain the ambition of creating and maintaining the finest collection of engineering literature in the world, supplemented by the current periodicals, and all the patents relating to invention in the arts and sciences. Provision is being made for special research accommodation, working-alcoves, photographic reproduction, drawing and similar library-work. Commanding

magnificent views of Greater New York and vicinity in every direction, the Library is retired, quiet, free from noise and dust, an ideal haunt of the student and man of research; while open at all times to any reader. In view of the proximity of the new Public Library, the Engineering Society Building with its unequaled collection of scientific and industrial data becomes at once a vital and important center of the highest value for the diffusion of useful knowledge, and the two libraries supplement each other.

A bronze bust of Mr. Carnegie, executed especially for the building by Mrs. E. Cadwalader Guild, a well-known sculptor, from sittings, and presented by the present and past officers of the Founder Societies, stands at the eastern end of the Library, facing toward the main entrance from the elevators.

The Contractors and Sub-Contractors.—The following is a list of the contractors, etc., employed in construction of the building: General contractor, Wells Brothers Co.; heating and ventilating, G. A. Suter & Co.; electrical work, Western Electric Co.; fixtures, Mitchell Vance Co.; plumbing, James McCullagh; furniture and carpets, W. & J. Sloane; shades, Simpson-Crawford Co.; library furniture, Library Bureau; book-stacks, Art Metal Construction Co.; auditorium chairs, American Seating Co.; lecture-room chairs, Readsboro Chair Manufacturing Co.; demonstration-tables, L. E. Knott Apparatus Co.; stereopticon, Charles Beseler Co.; stereopticon-screen, Journeay & Burnham; bronze tablets, J. Massey Rhind, sculptor, and the Roman Bronze Co.; steam-table, Bramhall, Deane Co. The following is a list of the sub-contractors, etc.: Elevators, Otis Elevator Co.; electric pumps, Worthington Pump Co.; mill-work, Batavia & New York Woodworking Co.; ornamental iron- and bronze-work, Winslow Brothers Co.; decorations and general painting, W. P. Nelson Co.; special metal doors, Dahlstrom Door Co.; New York Central Metal Co.; Van Kannel Revolving Door Co.; ornamental stucco-work and plastering, McNulty Brothers; marble- and mosaic-work, Empire City Marble Co.; ornamental brick, Fiske & Co.; granite work, Webb Pink Granite Co.; tile wainscoting, Frank L. Davis; coffer- and roofing-work, James White Co.; weather strips, Noiseless & Draughtless Door & Window Cushion Co.; leather-covered doors, Frank Fetzer; filters, Roberts Manufac-

turing Co.; fireproof windows, Manhattan Fireproof Door Co.; fireproof doors, Howells & Lawrence; ornamental terra cotta, Conkling-Armstrong T. C. Co. and R. Gustavina Co.; window- and door-glass, Benjamin Griffen and Pittsburgh Plate Glass Co.; metal lath and furring, A. Oliver & Co.; ornamental stone-work, James Gillies & Sons; parquette floors, J. B. Shaw & Co.; finishing-hardware, Yale & Towne Manufacturing Co.; fireproof floors, National Fireproofing Co.; plumbing-fixtures, Henry Huber & Co.; mail-chutes, Cutler Manufacturing Co.

COLLECTIVE INDEX OF THE TRANSACTIONS, VOLS. I.–XXXV.

A new Index of the *Transactions*, Volumes I. to XXXV., is now being prepared, and will probably be ready for distribution during the coming summer. The Index will be about the size of the average volume of the *Transactions*, and will be bound in cloth and in half morocco.

The price of the cloth-bound copy is $5, expressage prepaid. Half morocco binding will cost $1 extra.

It is very desirable that all who wish to purchase this Index will notify the Secretary's office promptly, sending a check, money-order or draft, made payable to the American Institute of Mining Engineers.

LIBRARY.

The library of the American Institute of Mining Engineers, together with the libraries of the American Society of Mechanical Engineers and the American Institute of Electrical Engineers, was opened officially on the day of the dedication of the United Engineering Society Building, April 16, 1907.

Members of the Institute will be afforded all the privileges of the library extended at 99 John street, and, in addition, will be allowed to consult the libraries of the other Founder Societies.

These libraries are for reference only, and not for circulation, and are open week days from 9 a.m. to 5 p.m.

The issue of *Bi-Monthly Bulletin*, No. 12, November, 1906, contained a list of volumes and numbers needed to complete the sets of serial publications in the library. A prompt response to this appeal was received; but there are still many gaps to be filled. As there are several hundred duplicates in the library, the librarian would be very glad to secure back volumes and numbers of titles in the above-named list, on an exchange basis. Correspondence regarding the matter is respectfully solicited by the Secretary of the Institute.

Accessions.

From January 15 to May 1, 1907.

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AMERICAN SOCIETY FOR TESTING MATERIALS. *Proceedings of the Ninth Annual Meeting.* Volume 6. Philadelphia, 1907.

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ASSOCIATION FOR THE PROTECTION OF THE ADIRONDACKS. *A Brief Review of the Depredations upon the Adirondack Forests, Accomplished or Attempted During the Past Few Years.* 19 p. 8vo. New York, 1907.

——— *The Legislature of the State of New York for* 1907. 7 p. 8vo. New York, 1907.

Robert Allen.

CHAMBER OF MINES OF WESTERN AUSTRALIA. *West Australian Metallurgical Practice.* 186 p. il. pl. maps. 4to. Kalgoorlie, 1906.

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MISSOURI—BUREAU OF GEOLOGY AND MINES. *Biennial Report of the State Geologist*, 1905, '06. 8vo. Jefferson City, 1906.

Bureau of Mines of Ontario.

ONTARIO—BUREAU OF MINES. *Report.* Vol. 15, pt. 1. 8vo. Toronto, 1906.

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CALIFORNIA STATE MINING BUREAU. *Bulletin* Nos. 44, 45. 8vo. Sacramento, 1906, 1907.

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U. S. COMPTROLLER OF CURRENCY. *Annual Report*, 1906. 8vo. Washington, 1906.

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U. S. GEOLOGICAL SURVEY. *Mineral Resources*. 1905. 8vo. Washington, 1906.

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NORWAY-STATISTISKE CENTRALBUREAU. *Statistisk Aarbog*, 1906. 8vo. Kristiania, 1906.

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Mijnordonnantie (Staatsblad, 1906). 213 p. 8vo. Batavia, 1906. (Staatsblad van Nederlandsch-Indie No. 434.)

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UHLAND, S. *Industrielle Rundschau.* Vol. 3. 4to. Leipzig, 1889.

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GARVIN CYANIDE EXTRACTION COMPANY. *Bulletin* No. 3. 8vo. Portland, n. d.

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G. S. Godard.

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HOFMANN, O. *Hydrometallurgy of Silver.* x, 345 p. 8vo. New York-London, 1907.

[SECRETARY'S NOTE.—This is another of the important treatises with which Americans are enriching technical literature, as they have already improved—sometimes even revolutionized—technical practice. Mr. Hofmann has been for nearly a quarter-century a member of the Institute, and has made himself, by a career covering a still longer period, a recognized authority in the department of which he writes. The news that he has made known in this book, the results of his studies and experiments, will be good news to his many colleagues throughout the world. The contents of this volume comprise Part I., on the chloridizing-roasting of silver-ores (including chapters on the theory of the process, the crushing of the ore, the use of salt, the loss of silver by volatilization, methods of roasting, fuel-consumption, hand-reverberatories, mechanical roasting-furnaces, the collection of flue-dust, sulphating-roasting, the chloridizing of argentiferous zinc-lead ore in the Stetefeldt and in other furnaces, and the chloridizing of calcareous ores), and Part II., on the extraction (including chapters on lixiviation with sodium hyposulphate, the precipitation of the silver, the treatment of the precipitate, the construction of troughs, trough-lixiviation, the Russell and Kiss processes, the Augustin process, extraction with sulphuric acid, the Ziervogel process, the treatment of silver-ores rich in gold, and the cyanidation of auriferous silver-ores). The volume is handsomely printed, with many pertinent engraved illustrations.—R. W. R.]

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U. S. INTERSTATE COMMERCE COMMISSION. *Twentieth Annual Report*, 1906. 8vo.

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Dr. Joseph Struthers.

NEW YORK STATE MUSEUM. *Bulletin* No. 98. 8vo. Albany, 1905.

WHITLOCK, H. P. *Minerals from Lyon Mountain, Clinton County.* pp. 55–96 pl. 8vo. Albany, 1907.

Technical Supply Company, Scranton, Pa.

Examination Questions for Certificates of Competency in Mining. 532, xxxvi, p. 8vo. Scranton, 1907. Price, $3.50.

[SECRETARY'S NOTE.—This book belongs to a peculiar class, the only other examples of which known to me have been similar manuals for the aid of law-students, seeking admission to the bar. The occasion for it is furnished by the existence in several States, notably in Pennsylvania, of official positions connected with mining, steam-engineering, etc., the candidates for which are obliged to pass a preliminary examination. Everybody who has had that experience knows what dread it inspires beforehand, and what regret may follow it, if the candidate has prepared himself in total ignorance of what he had to expect, or if he happened to encounter questions on the very points he had neglected to cover, while laboriously mastering other things, his knowledge of which he enjoyed no opportunity to display. Of course, it would be wrong to furnish to a candidate in advance the exact questions which would be put to him, so that he could "cram" on these, though densely ignorant of all others. But it is not wrong to give him encouragement and guidance by showing him the general nature of such an examination, and indicating to him the form of satisfactory answers. That is what this book does, and does very well indeed. Incidentally, it shows what sort of knowledge a man ought to possess, and keep fresh in mind for handy reference, no matter how vast and recondite may be his other knowledge. The volume contains aid of this nature on surveying, geology and prospecting, mine gases, safety-lamps, the inspection and regulation of gaseous mines, explosives and blasting, principles and calculations of mine-ventilation, the comparison of air-ways, splitting air-currents, conducting air-currents, measuring and testing air-currents, establishing a circulation of air in mine-ventilation, mine-fans, practical points in mine-ventilation, opening a mine, methods of working coal-beds, coal-pillars, timbering, steam and steam-boilers, steam-engines, hoisting, haulage, hydraulics and pumping, compressed-air, electricity, the duties of mine-officials, together with a statement of the regulations governing certificated positions in Alabama, British Columbia, California, Colorado, Idaho, Illinois, Indiana, the Indian Territory, Iowa, Kansas, Kentucky, Maryland, Michigan, Missouri, Montana, New Mexico, New York, Nova Scotia, Ohio, Pennsylvania, Tennessee, Utah, Washington and West Virginia. This final summary is not only most valuable, but also, so far as I know, not to be found, as a whole, in any other book.—R. W. R.]

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EXERCISES IN DEDICATION OF THE ENGINEERING SOCIETY BUILDING, New York, April 16 and 17, 1907.

[SECRETARY'S NOTE.—Since the Committee on Publication of United Engineering Society, will issue a memorial volume reporting these proceedings in full, an outline only will be here given. The sessions were held in the Main Auditorium.—R. W. R.]

COMMITTEES.

EXECUTIVE.—J. W. Lieb, Jr., *Chairman;* C. W. Rice, *Secretary;* John Hays Hammond, Chas. Wallace Hunt, F. R. Hutton, Charles Kirchhoff, T. C. Martin, E. E. Olcott, Chas. F. Scott, Samuel Sheldon, Ambrose Swasey.

INVITATIONS.—R. W. Raymond, *Chairman;* Charles Kirchhoff, *Secretary;* A. C. Humphreys, Robert W. Hunt, L. B. Stillwell.

PROGRAM.—A. R. Ledoux, *Chairman;* C. W. Rice, *Secretary;* Theodore Dwight, Chas. Wallace Hunt, T. C. Martin, Ralph W. Pope, Joseph Struthers.

WAYS AND MEANS.—James Douglas, *Chairman;* A. R. Ledoux, *Secretary;* H. R. Brown, J. M. Dodge, C. L. Edgar, John Hays Hammond, W. M. McFarland, E. E. Olcott, Samuel Sheldon, J. G. White.

HISTORICAL AND PUBLICATION PRESS.—T. C. Martin, *Chairman;* Albert Spies, H. H. Suplee.

RECEPTION.—J. W. Lieb, Jr., *Chairman;* C. W. Rice, *Secretary;* E. D. Adams, E. R. Archer, B. J. Arnold, J. C. Barclay, S. W. Baldwin, W. J. Baxter, N. F. Brady, J. I. Beggs, Alexander G. Bell, William P. Blake, J. A. Brashear, C. F. Brush, Andrew Carnegie, R. C. Carpenter, J. J. Carty, John A. Church, Walton Clark, Thos. F. Cole, C. A. Coffin, G. H. Condict, F. B. Crocker, A. C. Dinkey, Cleveland H. Dodge, J. M. Dodge, James Douglas, Alexander Dow, Theodore Dwight, T. A. Edison, Anton Eilers, L. A. Ferguson, J. R. Freeman, John Fritz, James Gayley, Eugene Griffen, James D. Hague, John Hays Hammond, C. H. Haswell, John B. Herreshoff, J. B. F. Herreshoff, P. C. Hewitt, C. A. Hexamer, H. M. Howe, A. C. Humphreys, Chas. Wallace Hunt, Robert W. Hunt, F. R. Hutton, W. J. Jenks, R. E. Jennings, F. W. Jones, Hon. Lord R. Kelvin, James F. Kemp, W. C. Kerr, Charles Kirchhoff, E. D. Leavitt, Albert R. Ledoux, Frank Lyman, Emerson McMillan, C. O. Mailloux, T. C. Martin, G. W. Melville, R. D. Mershon, C. H. Morgan, T. E. Murray, E. E. Olcott, F. S. Pearson, F. A. C. Perrine, R. W. Pope, Sir William Preece, M. I. Pupin, J. C. F. Randolph, R. W. Raymond, T. F. Rowland, Sir David Salomons, W. L. Saunders, C. F. Scott, Coleman Sellers, C. H. Sharp, Samuel Sheldon, Paul Spencer, C. P. Steinmetz, L. B. Stillwell, H. G. Stott, Joseph Struthers, H. H. Suplee, Ambrose Swasey, J. E. Sweet, F. H. Taylor, F. W. Taylor, C. A. Terry, P. H. Thomas, Elihu Thomson, H. R. Towne, W. R. Warner, Geo. Westinghouse, S. S. Wheeler, Arthur Williams, C. C. Worthington.

At the first session, beginning at 3 p.m. on Tuesday, April 16, Mr. Charles Wallace Hunt, past-President of the American Society of Mechanical Engineers, and representative of the Executive Committee of United Engineering Society, took the chair, and prayer was offered by Rev. Edward Everett Hale, D.D., Chaplain of the United States Senate.

Mr. T. C. Martin read a congratulatory letter from Theodore Roosevelt.

Señor Henrico Creel, Minister Plenipotentiary and Ambassador Extraordinary of the Republic of Mexico, read a personal message from General Porfirio Diaz, President of the Republic of Mexico.

A message was read from Earl Gray, Governor-General of the Dominion of Canada, who was expecting to be present, but had been prevented by an unfortunate delay of his railway train.

Mr. Martin read a letter from the venerable Charles H. Haswell, "the dean of the engineering profession," now in his 98th year, extending hearty congratulations and regretting his inability, by reason of temporary illness, to be present.

The chairman, with a few words of reminiscence, presented Mr. Charles F. Scott, past-President of the American Institute of Electrical Engineers, and "the tireless Chairman of the Joint Conference and Building Committee from its organization, four years ago, to the present time."

Mr. Scott delivered an interesting address, narrating the history of Mr. Carnegie's gift, and depicting both its present importance and its unlimited future possibilities. In the course of his remarks, he made an allusion to the venerable "Uncle" John Fritz (present in the audience) which brought the assembly to its feet, with round after round of enthusiastic applause.

The chairman, with happy allusion to the fact that through the skill and fidelity of the architects, the building was a monument, not only of architectural beauty but also of good engineering, having been erected at a cost within the amount first provided for it, and occupied within a few weeks after the builders' contract-time had expired, proceeded, in the name of the Building Committee, to deliver to Mr. E. E. Olcott, past-President of the American Institute of Mining Engineers,

and President of United Engineering Society, the key of the building, which Mr. Olcott received with appropriate remarks.

[This is a Yale & Towne key, with a medallion handle, made by Tiffany & Co. of native gold from the North Star mine, Grass Valley, Cal., presented by Mr. James D. Hague, for many years President of the North Star Mining Company, and now a Vice-President of the American Institute of Mining Engineers. On one side, the medallion bears the symbols of the three societies. On the other side, together with appropriate ornamentation and inscription, and under a piece of quartz crystal from the Mother Lode, California, are several scales of the gold panned by John Marshall in January, 1848, from Sutter creek, California—the gift of Mr. George F. Kunz, a member of the American Institute of Mining Engineers.]

The chairman then introduced Mr. Andrew Carnegie, who was received with immense and long-continued applause, after which he spoke as follows:

ADDRESS BY MR. CARNEGIE.

Mr. President, Mr. Ex-President, Mr. Present President, and Uncle John Fritz:

The Scotch have a saying, and they have many wise sayings, that fools and bairns should never see a thing half done. I don't wish to associate myself either with fools or bairns, but I think I may add that donors should never see a thing half done. I went to Pittsburg the other day knowing nothing of what I should find; I had sedulously kept away from the fairy palace that they were erecting; I knew nothing of it, but when I got there I found a palace that Aladdin might have brought forth, and so beautiful that I felt that I was in a dream. I come here to-day under somewhat similar circumstances, and am brought into this beautiful hall, exquisite in every part, and face to face with this splendid audience. Well, it gives point to what Mrs. Carnegie said when I was expressing to her that I was totally unable to realize what part I had taken in creating a palace; I said to her I felt like Aladdin rubbing the lamp, and she said, "Yes, and we didn't even have to rub the lamp." (Laughter and applause.) But as the proceedings went on at Pittsburg and I had the great pleasure of addressing those there present, and among the audience those who had created the

palace, this thought occurred to me: It is the spirit with which men are enthused that does the work; the sense of co-operation, and the realization that really the performance of great and benevolent work raises the men who participate in it far beyond any personal work for themselves. The safety of human society lies just here. Whenever men coalesce to do some good work a unification takes place and consolidation; and whenever men meet to conspire against the public good to do some evil, they find themselves unable to trust each other. Segregation takes place and they fail. That is the reason why we needn't lie awake nights and worry about the future and about what problem society is going to meet. As sure as the sunflower turns towards the sun and receives its light and heat, just as surely human beings march onward and upward with their faces to the sky to do better things. Much that I was taught in my youth has passed away; much that I once thought of I have had to discard; but here is the rock upon which I rest and meditate and find happiness. We can't deny this—that quite apart from whatever evil exists, there is this principle of improvement inherent in us. To-day is better than yesterday and to-morrow will be better than to-day. So I look forward to the future of this building, and I know that the organizations to whom it is devoted will advance and continue to meet the developing needs of the age as the years roll by. That is comforting, that is encouraging, and that is a reflection to which I shall always return and upon which and in which I shall always find rest.

I congratulate you upon your architects. This architectural selection was just in accordance with my ideas. I have never given a building in my life that I could control except by competition. I don't want names, but architects; I don't want everything that an architect may present, for Homer nods and even Shakespeare nods; I want to see what a man brings, and I don't want to see what his name is or to know his name. There were twenty-six plans submitted, as you have been told, and there was a committee to pass upon them, and then there was a very wise and good man as a sort of censor over the plans, Professor Ware, and he chose two plans—one for the Engineers' Club Building and the other for this building—as being the best, and, by the way, the committee had previously

agreed upon those two plans. Well, who were the architects —some well-known great firm? No, they were two young men that had never been heard of in New York, I think. There is the proud father of one of them (here Mr. Carnegie turned to Dr. Hale and bowed), and there is a lady sitting up there (pointing to Mrs. Carnegie, who sat in the balcony) who is also proud, for the other successful architect was Mrs. Carnegie's brother.

Well, gentlemen, that is triumphant democracy. No pedigrees, no social influence, count for much in the architectural profession. Nothing but real merit. And with the engineers who act it shows you that they were true to the principles of their profession. The engineer works from morning until night unvaryingly for what is true. Two and two make four, and one five, all the time. That gives the engineer his character. No fraud, no deviation, no evasion, but march, march, march, true to the line all the time.

I wish to speak of one remark that the President makes about American characteristics, and you also, Mr. Chairman, have spoken of my reference to the spirit of union in co-operation. One of the great advantages which the American has over the man of any other country lies in his ability to and in his disposition for co-operation. Our political institutions which make every man the equal of any other man, every man's privilege any other man's right, lie at the foundation of that characteristic. Americans all meet upon a plane of equality; one man is just as good as another man, and therein he meets in a sense of brotherhood, and the committees that you hear about acting by "unanimous vote" are the outcome of that. I venture to say there never was a case like that with the Britons or the Scotch, especially with the Scotchman.

"Where are you going, Sandy?" said one Scotchman to another.

"Doon to the club," said Sandy.

"An' wha' foor?"

"Just to contradeect a wee bit."

That is the way it is over there.

Now, the American with his political institutions, with the blending that he has in him of all nations, is a man who partakes of the best quality of each of the other nations. It is from this fact that you find co-operation, and I speak with

great experience, knowing manufacturers and engineering societies on the other side, every one of them standing apart and unable to get together, and here the American calmly sits down and discusses and co-operates and evolves. If there be any guests here from the other side—yes, I see there is one (pointing to Sir William H. Preece)—I think he will carry home with him from what he heard in Pittsburg—for there was a similar story there, too—this impression, and that he will say, "Well, these Americans begin even in business to feel more of the spirit of brotherhood than we do."

We only hate those we do not know, is quite true. That is my experience. The older I get—no, I mean the younger—and the more experience I have with men and with women, the more I am convinced of the truth of the fact that you only have to know the virtues of your fellow men to find that they are all brothers. That is the reason that I am a great advocate of the peace of the world. It isn't enough for individuals to feel the spirit of brotherhood as all Americans do, but we must enlarge it and realize the great truth that all men of all nations are really our brothers. (Applause.)

I have no more to say to you than to again express my surprise that the little conversation that Uncle Fritz and these gentlemen and myself had has resulted in such a magnificent building as this, and more than that, with proving to the world that the Engineering Societies of America are one band of brothers, with headquarters here, to which every one of them is loyal. I thank you very much.

The chairman then introduced President Arthur T. Hadley, of Yale University, who delivered the following address:

ADDRESS BY ARTHUR T. HADLEY.

A building like this is the best monument of what the nineteenth century has accomplished.

The really important part of the history of a nation is the development of its ideals and standards. The specific things that it does are important not so much for their own sake, as for the sake of the evidence they give concerning the trend of a nation's thought. It is not the magnitude of the individual battles which makes a war worth reading about. It is the ideas under

which the war is conducted and the constitutional principles for which it is fought. It is not the census figures which decide whether a nation is great or small. It is the industrial methods and educational ideas which these census figures indicate. And in like manner it is not the buildings and machines and railroads and mines which constitute the important part of the history of the engineering profession. A book might give a good description of a thousand of these great engineering works, and yet fail of being in any sense a true history of engineering progress. The thought of the successive builders and the influence of that thought upon the conduct and ideals of other men are the things that we really care about. The story of the concrete achievements that have dazzled the eye of the world is but the unimportant and superficial part of the history. The real thing for which we care, the thing that helps us to understand the past and inspires us with hope for the future, is the story of the men who did the things—their struggles and their discoveries, their trials and their successes.

The men who did more than anything else to make the nineteenth century different from the other centuries that went before it were its engineers. Down to the close of the eighteenth century the thinking of the country was dominated by its theologians, its jurists, and its physicians. These were by tradition the learned professions; the callings in which profound thought was needed; the occupations where successful men were venerated for their brains. It was reserved for the nineteenth century to recognize the dominance of abstract thought in a new field—the field of constructive effort—and to revere the trained scientific expert for what he had done in these lines. Engineering, which a hundred years ago was but a subordinate branch of the military art, has become in the years that have since elapsed a dominant factor in the practice of every art where power is to be applied with economy and intelligence.

A building like this is therefore the symbol of all that is most distinctive in the thought of the century that has gone by. A hundred years ago we might have had a building in honor of theologians, or of lawyers, or of physicians; but one that symbolized the achievements of the engineer was beyond man's dreams, because the world at large had neither felt the

need of his work nor dreamed how soon it would be seeking his leadership.

I have spoken of this building as a monument; but that after all is not the proper word. A monument implies that a man is dead, or at any rate that he has so nearly reached the limit of his growth that he might just as well be dead. Looked at in this way the engineering profession wants no monument. It has not yet reached the limit of its growth. It has not come to the time when a complacent survey of the past will take the place of toilsome planning for the future. Not a headstone do we want, but a milestone—a point at which our measurement of what has been already done serves as an inspiration for the journey yet to be traversed. We may take this opportunity for a brief review of what has been done in engineering and other allied professions; but the engineer who is worthy of his calling will value that review most highly if it is made a means of calling his attention to that which yet remains to be done.

A hundred years ago there was a sharp separation between scientific theory and commercial practice. There was not a great deal of science anyway, outside of mathematics and astronomy; and what there was was underrated by men of affairs. In those days when a man said he was practical it meant that he was not theoretical; that he didn't know science, and didn't want to know it, and didn't want to have any man around that did know it. The men of that day trusted to two guides: inherited prejudice, and individual experience. The more enlightened among them used experience to correct prejudice; the rank and file of them used experience to reinforce prejudice; and that was about all the difference. The value of generalizations, except in religion and in statecraft, and in some few branches of medicine, was not recognized by anybody.

The great element of progress in the nineteenth century has been the recognition on the part of mankind in general of the value of scientific generalizations in every department of human conduct. Our science has become sounder, our understanding of its applications clearer; and the public has recognized that scientific conduct of a business means the substitution of universal experience, learned with difficulty and applied with toil, for the narrower range of individual experience which was at

the disposal of the so-called practical men of fifty or a hundred years ago. Of this change the engineer is the representative and the leader. He it is that makes physical science in its various lines applicable to the complex problems of construction and development. He it is who has paved the way for the recognition of the technologist and the expert in every line of human industry. He it is who has shown how mathematics, instead of being an abstract discipline, apart from everyday human affairs, may become the means of applying truths for a long time remote and undiscovered to the practical affairs of the world in which we live. Not the buildings that you have built, gentlemen; not the railroads that you have planned; not the machines that you have invented, represent your greatest achievement. Yours is the proud boast of having in one brief century established science as the arbiter of the material affairs of mankind, and of having enforced her worship upon a world once reluctant but now gloriously admiring.

What then, you will ask: is there anything which remains to be done comparable in importance to this? Yes, there is. An equally large part—perhaps in one sense a much larger part—of your professional duty yet remains to be accomplished. It is not enough to have technical training. It is not enough to know the special sciences on which the practice of a profession is based. A man ought to have clear conceptions of the public service which his profession can render and the public duty which its members owe. Thus, and thus only, can the engineer, the lawyer, the physician, or a member of any other learned profession, rise to the full dignity of his calling.

For there are two quite distinct qualities which must be combined in order to secure the best professional service; two quite distinct tests which work must meet in order to be pronounced first class. One of these is the technical standard; the other, for want of a better word, may be called the ethical standard. The man who wishes to build a good railroad must not only lay it out according to the rules of the surveyor's art, with proper curves and grades and bridges which will not fall, but he must also have some intelligent regard to the needs of the population, the safety of travel, and the many other factors which

determine whether a railroad shall be a work of public use or a source of industrial bickering and financial disaster. This combination of public and private demands is not peculiar to engineering. It can be illustrated in every other profession of importance. It is not enough for the lawyer to give advice which shall be technically sound and which shall enable his clients to keep out of jail: he must learn to take a large view of the law as a means of public service instead of private gain. It is not enough for the physician to know how to cure specific diseases: he must know how to care for the larger problems of public health, and to use the resources of the community in a way to meet as fully as possible its sanitary needs.

This larger view of professional obligations is not so fully recognized as it should be. We have in the nineteenth century made so much progress in the technical training of doctors and lawyers and engineers that we sometimes forget that there is need of anything more than technical training. We have let the old idea of public leadership, which was prominent in the minds of the great professional men of past centuries, give place to another and narrower ideal which is fully satisfied when a man has made himself a technical expert. Many a man of real eminence in his calling deliberately rejects the wider conception of professional duty which I have here indicated. Perhaps he recognizes the claims of public service, perhaps he does not; but in any event he believes that these claims rest upon him as a man rather than as an engineer or a lawyer. In his professional capacity he says he is hired not to tell what the law ought to be, but what it is; not to advise how a railroad can do the most public service, but how certain men with certain ideas of their own can best use the differential calculus to get these ideas carried out. This is perhaps the prevalent view of professional ethics to-day. I believe that it is a wrong view, which must menace not only the influence and standing of the professions themselves, but the general interests of the republic.

In the first place, a man who believes that he is hired to carry out another man's ideas can never claim a position of actual leadership. He remains a paid servant; highly paid, doubtless, because he is possessed of a kind of skill which is very unusual, but nevertheless a servant, bound to carry out

the wishes of his master. A group of professional men which regards this as a proper view thereby forfeits the claim to stand in the first rank socially and politically, and voluntarily accepts a position of the second rank. I do not believe that the engineers of America want to do this. It has been said that engineering is the handmaiden of commerce; but I do not believe that the men who have planned and dedicated this building will be satisfied with any handmaidenly conceptions of what their successors ought to be. If, for a moment, in our zeal for new technical developments, we have let our responsibilities as public servants fall out of our hands, I feel sure that we shall be ready to take them up again as soon as our eyes are opened to the real situation.

For mere technical achievement is not the thing that endures. Among the peoples of the ancient world, I suppose that there were no engineers equal to those of Egypt. Considering the means at their command, the things that they did were absolutely extraordinary. They did some things which, even with the means at our command, we can hardly duplicate. But they used their abilities in the service of a dominant priestly caste; and therefore, while their work fills us with admiration, it does not appeal to us as does the work of the Roman engineers a few centuries later, who built roads and aqueducts and bridges, and thus took the lead side by side with the Roman lawyers in establishing the basis of modern civilization. The roads and bridges of Rome, simple and straightforward as they are, constitute a more enduring monument to the Roman engineers than all the obelisks and pyramids that were ever erected.

For their own sake, then, and for the sake of the enduring quality of their work, we can appeal to the engineers and lawyers and physicians to see that it is adapted to public ends. We can reinforce this appeal by a yet stronger one on behalf of the American commonwealth as a whole. For the development of technical ideals and standards in our various professions during the last few centuries, to the neglect or exclusion of ethical ones, is constituting a very serious public danger.

A commonwealth like that of the United States is necessarily governed by public opinion. Courts may formulate this opinion. Legislatures may pass rules to give effect to it. Police may

enforce its demands against the recalcitrant. But the governing power rests in the intelligent public opinion itself. When that opinion ceases to be intelligent and powerful, freedom becomes a mere name. Now a serviceable public opinion of this kind can only be formed when intelligent people, technically trained for different lines of life, seriously try to find out how their work can be made to meet the public needs. They are the only ones who can do this well. If it is done by anybody else it will be done badly. If the lawyers as a class try to keep the law in line with the demands of intelligent public opinion, we can get good law. But if lawyers are content to see the law perverted to private ends, and judges take refuge in technical construction of precedents, without full regard to the needs of the existing situation, legislatures will step in to create a chaos of conflicting laws which is worse than no law at all. In like manner, if our engineers get their own minds clear, and get the public mind clear, as to the political economy of the properties intrusted to their charge and the ethics of their management, they can forestall those conflicts which now threaten to break out at every moment. But if the members of a profession whose advice is necessary in order to a clear understanding and wise settlement of these problems retire from the field of action, the matter will be settled by those whose interests are more selfish and less far-sighted. There are three professions to-day which do not regard themselves as servants, but as masters—the financier, the journalist, and the politician. If the engineer and the lawyer accept positions as servants, simply putting their technical knowledge at the disposal of merchant, journalist, or politician who will pay the highest price for it, it is not simply a confession of inferiority, it is a dereliction of public duty.

Do you say that it is impossible for a single man or a group of men to remedy these evils? Look at the career of Albert Fink, who in 1874, when he was an engineer on the Louisville & Nashville Railroad, made a study of the cost of transportation which has been at the basis of all the intelligent management of the traffic departments of railroads from that time to this.

Of course, Albert Fink was a rare man. He could do things that some of the rest of us cannot. But I verily believe that

if our professions could awake to the necessity of broad ideals like those of Fink the greatest dangers which threaten the American commonwealth would be fairly met, and the men who met them would be given the positions of power and trust which they had proved themselves worthy to hold. Nobody is satisfied to-day with the struggle between individualism and socialism, between financier and politician, between Wall Street and Washington. The men who are engaged in this conflict are for the most part heartily sick of it. Let a man or group of men arise who add to their technical knowledge a readiness to use that knowledge in the public service, and people will be eager to put them in charge and to follow where-ever they lead. We have outgrown the day when a little common sense was sufficient for managing the affairs of the nation. They are become too complex; and this complexity gives the engineer, if he will add to his training in mathematics a training in ethics and political economy and the fundamental principles of the law, an opportunity such as never before existed to claim and receive the position which rightfully belongs to him.

There arises now and then among our engineers a man with this quality of looking into the future—call it genius, call it insight, call it imagination. One of your own members said in a memorable speech that the thing which distinguishes a man of the first rank in his profession from a man of the second rank is the possession of this quality of imagination. Unfortunately it is rare. We cannot all of us have it. But we can have more of it than we now have, if we will modify our training and widen our standards of professional success. Excellent as is the course in our technical schools, it does tend to have a narrowing effect instead of a broadening one. The ideals of our engineering societies are high, but they are not always as broad as they might be. The widening of the course in the schools and greater readiness in our associations to recognize services which we now call non-professional, will, I am convinced, do more for the engineers and more for the community than would be represented by ten years' progress in mining or machinery and the various developments of applied science.

We celebrate to-day, and we are justified in celebrating, the

recognition of science as a necessary guide in the conduct of the material affairs of each man's business. Half a century hence, when our descendants shall meet in this building or some yet greater building, I am confident that they will celebrate a yet greater thing—the recognition of the right of men of science to take the lead in enlightening the thought of the people on public affairs and the responsibility of filling the highest positions in the service of the commonwealth.

Tuesday evening was devoted to social receptions of members of the three "Founder Societies," their ladies, and invited guests. From 9 to 10.30 p.m., a general reception was held in the Main Auditorium by the Presidents of the three Founder Societies and the Chairman of the Executive Committee of United Engineering Society, with their wives, as follows:

Dr. and Mrs. John Hays Hammond, A. I. M. E.; Dr. and Mrs. Frederick R. Hutton, A. S. M. E.; Dr. and Mrs. Samuel Sheldon, A. I. E. E.; Mr. and Mrs. John W. Lieb, Jr., U. E. S.

At 10.30 p. m., a special reception was held at the rooms of each of the "Founder Societies" by the officers of the society.

The building, including the Libraries on the 12th and 13th floors, was thrown open to the inspection and admiration of guests; music was furnished on the Auditorium, fifth and Library floors; and refreshments were served during the evening in the two beautiful smaller auditoriums on the fifth floor.

At the second session, held on Wednesday afternoon at 2.30 p.m., Mr. J. W. Lieb, Jr., Chairman of the Dedication Committee, presided, and opened the exercises with an appropriate address, extending, in the name of the Founder Societies, a hearty welcome to the representatives of sister societies and institutions of learning at home and abroad, and calling upon the Presidents of the Founder Societies for further remarks.

The following addresses were delivered by Dr. Samuel Sheldon, President of the American Institute of Electrical Engineers; Dr. Frederick R. Hutton, President of the American Society of Mechanical Engineers; and Dr. John Hays Hammond, President of the Council of the American Institute of Mining Engineers.

ADDRESS BY DR. SAMUEL SHELDON.

Even a casual visitor to the edifice whose dedication is the occasion of the present festivities, must be impressed by its simplicity, its beauty, and its substantiality. The personnel of the executive departments of the associated societies that have here domiciled themselves recognize its fitness and its spaciousness. All these qualities will endure except the last. The future will doubtless bring a congestion of occupancy which seems to be an inevitable metropolitan characteristic.

The Founder Societies at the present time have a total membership of nearly 12,000. Of these members more than 15 per cent. live in New York City or in its vicinity, and to them the building is accessible. Eight Associate Societies who are also at home here have a membership of approximately 4,000, about 40 per cent. of whom dwell in this vicinity. An inspection of the curves of growth of membership in the three Founder Societies shows that the present enrollment will be doubled in 1920, if past policies of management be maintained. Even times of financial depression do not lessen the membership but lessen its rate of growth. But the short period of joint occupancy just elapsed has evidenced a stimulation to increased activity which if maintained will make membership more desirable, and a greater increment may be expected.

During the last few years there has been a rapid growth in civilization: commerce, traffic, manufactures, organization, fortunes, knowledge, and individual efficiencies have increased. Excessive and extraordinary growth has resulted from the efforts of electrical engineers. Doubtless this is due to the youthfulness of the profession, whose oldest workers are not thinking of retirement, but, on the contrary, are enthusiastically and energetically productive.

Rapid growth and the character of his work necessitate that the engineer shall continually deal with the probabilities of the future. The remarkable economies resulting from an extensive engineering study based upon more or less uncertain future conditions of the problem of supplying telephone service in New York City twenty years hence, were called to the attention of the members of the American Institute of Electrical Engineers in a recent paper. We are all familiar with the

frantic struggles of engineers in charge of public utility central stations in their efforts to have modern apparatus manufactured, purchased, and installed quick enough to carry the ever-increasing load, but not so quick as long to stand idle and bring down the wrath of the financier. Reprehensible neglect to consider future conditions has resulted in an intolerable congestion of traffic in certain parts of this city. One cannot but admire the circumspection of the engineer who designed the bridges of the Western Railroad in Massachusetts so as to carry two tracks, although the practicability of the steam locomotive had not as yet been demonstrated and a double-track road had not been seriously contemplated. One cannot but regret that the engineer, who let his rule slip when he established the standard track gauge at 4 ft. 8½ in., had not the circumspection to let it slip in the other direction, that thereby might have been a present amelioration of the troubles of the Great. But all must congratulate those who engineered the construction of this building that they, like the Prophets of Biblical times, like all good generals in times of war, and like all good statesmen in times of peace, looked into the future in designing this, our home.

The constitution of the American Institute of Electrical Engineers states that "Its objects shall be the advancement of the theory and practice of Electrical Engineering and of the Arts and Sciences connected with the production and utilization of electricity."

The results of recent scientific investigation show that it does not lie within the power of man to produce electricity, and accumulated experience pre-empts to the electrical engineer the transformation of other forms of energy into electrical energy, its transmission and its adaptation for purposes of utilization. To the efficient, flexible, and convenient manner in which these things can be done is due the development of the art. The accomplishment of this work has brought about a natural classification of the workers into: first, those who design, manufacture, and adapt apparatus; secondly, those who purchase, erect, and install it; and, thirdly, those who operate and maintain it. Economic evolution has placed the manufacture in the hands of a few large corporations that require for their work the co-operation of all types of human endeavor. In their em-

ploy are to be found, besides those found in every other industrial organization, engineers of all kinds, even military and naval.

Because of the great magnitude of modern engineering undertakings and the desire for high efficiency, there is a marked tendency to intrust the purchase, erection, and installation of electrical apparatus to large engineering organizations. Such a one in the West, whose head is a prominent electrical engineer, includes in its staff one or more electrical, civil, mechanical, structural, sanitary, chemical, gas, hydraulic, mining, industrial, and operating engineers. The natural result of the existence of such an organized staff is the undertaking of other than electrical installations. A firm in New York City, besides installing electric railways, power and lighting plants, is engaged in the constructing of sewerage systems, and in the erecting of banks, theaters, hotels, terminal stations, and other large structures. To such an organization the financing and engineering construction of the Panama Canal would be a natural and a feasible undertaking.

To those engineers who are engaged in the operation of electrical plants generally falls the task of purchase, erection, and installation of additional equipment necessitated by growth. Upon their staffs are also to be found various types of engineers.

These instances merely illustrate the condition of man's limitations because of his environment, and emphasize that the social fabric rests upon the interdependence of individuals and the redemptive economy that results from correlation of individual efforts. Try as we may to limit the spheres of our activities and to direct the lines of our intellectual growth, the potentiality of its seeds is beyond our control, and fortunate are we that there now portends an appropriate nourishment in the intercourse between the cohabitants of our new home.

ADDRESS BY DR. FREDERICK R. HUTTON.

He who would fain speak in any adequate way as a representative of the profession of mechanical engineering and of its practitioners in the American Society must recognize that the field of his outlook is exceedingly broad.

The electrical engineer has made his own the field of trans-

mission of energy for light and power, and for transportation by railway, and for communication between individuals.

The mining engineer and metallurgist have conquered the winning of buried wealth from the earth and the process of making it available for industry, and the production of wealth.

The function of the mechanical engineer has, therefore, been to share with the civil engineer the industrial activities in the rest of the field of practical achievement.

If to the latter be assigned the permanent-way of the railroad and the highway and their bridges, the canal, the municipal field in water-works and draining and the designing of the braced structure as his specialties, there remains to the mechanical engineer the duty of generating or liberating power for all sorts and conditions of engineer, and the duty of design and creation of apparatus for the broad field of manufacturing. It would appear, therefore, that he will be most generally representative of mechanical engineering, who places himself in the area devoted to the generation of power, which underlies all production on a large scale. He is also the one who creates machinery and tools for manufacturing and production in all lines, and who concerns himself with the operation of such plants and the consequent creation of wealth. I believe that the mechanical engineer of the twentieth century is to be the manufacturing engineer.

If the foregoing be conceded, then the dedication of the Engineers' Building at this time emphasizes the noteworthy economic significance of such a building. It has become, therefore, the gift of a great producer to the great factors of production.

The owner of a mine is not enriched until by the expenditure of skill, power, and labor, the buried ore has been won and made available. The crude ore at the surface is not of full value until the engineer of transportation by land or water has brought it to the door of the metallurgical engineer, who, by expending skill, power, and labor upon it, changes it to useful metal. The metal is not of market value until the mechanical engineer by skill, power, machinery, and labor, has brought the metal to its merchant forms in which it can be sold and used.

In the next stage and after the purely productive process over which engineers have presided, will come the industrial or commercial application of the materials. For these, again,

it is the engineer who has created the need. The railway rail, the beam, the plate, the bar, the casting and the forging are all made and sold to meet the call of the designer, the builder, and the user of the constructive elements in modern production. For all the wealth represented in plant and product, it is an engineer who has signed the call. It is his rubbing of the Aladdin lamp of knowledge and skill, which has brought into existence the material result. It is a tribute to the insight and ideals of the donor of the building that he should have seen that by helping to foster the engineer himself, he has raised a most notable monument to economic betterment and the uplift of the community. The building, supplying facilities for engineers' meetings, for an engineers' library, and for the executive work of engineering organizations, has helped to raise and to advance the already exalted standard of that profession within its own bounds.

But the Engineers' Building has not alone a meaning and significance to those who are to be within it and who benefit so directly by its provisions for comfort and for progress. It has an external significance and a meaning to those who are without. It stands in dignity and majesty as a public building on an eminence to deliver to luxury and thoughtlessness its uplifting message. It stands to teach that wealth or mere accumulation does not create or perpetuate itself until it is used. All consequent possibility of culture, education, refinement, and art are latent in wealth, but lie hidden there until it is devoted to industrial production. Mere manipulation of securities or purely capitalistic financing does not produce wealth. In manipulation, wealth may change owners, but one is poorer because the other is richer. The Engineers' Building stands for the real creation of community wealth where a real asset of value is made to enrich both owner and community by multiplying itself in accordance with physical and economic law. No production of wealth is real or can continue which is in defiance of law or fact. The engineers for whom this building exists are students and practitioners of their craft and avocation in conformity with such law. Knowledge of such necessary laws lies at the base of the prosperity which the community enjoys.

This makes the Engineers' Building at once a beacon and a

plea for engineering education. This must be such training as shall fit the engineer to conduct continuous and successful production in accordance with the requirements of physical and economic law. The scientist and the laboratory worker and the man of affairs must be expected to discover, formulate, and apply these laws. The building is, therefore, a monument to what the engineering school and the scientist have done and are yet to do for the advancement of our civilization in educating its engineers.

Finally, the Engineers' Building stands to rebuke certain economic fallacies. It is a convincing answer to a contention that physical toil and manual labor of arm and brawn are the only real creators of wealth in the production process, and that the reward of toil is to be directed entirely to him who contributes bodily effort. It says to such a theorist that misdirected toil and labor, which goes for naught through ignorance of physical or economic law, will impoverish the community, not enrich it. Experiments are costly when at their basis lie assumptions contrary to fact and truth. Furthermore, labor must be organized and must be directed by knowledge; its tools and its operations must also be designed and planned on a basis of knowledge and experiment. The director and organizer of labor is, therefore, to be compensated both practically and in public consideration in proportion to his economic value. The engineer as a factor in production far transcends the significance of the mere craftsman, and this building evidences the truth and the fact. The economic future does not lie amid the dreariness of some of the contentions of the socialist. It lies in releasing more and more the human unit from the stress which we lay upon the beast of burden. In this releasing process the engineers will be inevitably the leaders.

In conclusion, therefore, I ask you to agree with me in these contentions three:

I. That this building is a gift to favor production as a factor in creating wealth, itself an antecedent to progress in art, civilization, culture, and literature.

II. That it should stand in its city as a monument for sound thinking on the position of the engineer and his relation to wealth and its production by knowledge and by skill working in accordance with natural law; and, therefore, for the significance of engineering education as favoring such sound thought.

III. That as a consequence of these the community as a whole as well as the organizations directly benefited by the building owe a debt of obligation and recognition to him who has made all this possible.

ADDRESS BY DR. JOHN HAYS-HAMMOND.

This is unquestionably the era of the engineer the world over, and especially is this true in respect of America. To the skill of her engineers in the exploitation of her unparalleled resources America owes her recognized pre-eminence in the industrial world.

In the development of new fields for industry, the engineer has played a conspicuous part. First comes the mining engineer, *facile princeps*, the pioneer of civilization, penetrating the dense jungles of the tropics and traversing the ever-frozen North in the quest for gold. His indomitable pluck, his indefatigable energy, and his professional skill have sometimes resulted in the discovery of a new territory for human activity, and have sometimes, alas! availed naught save the adding of his name to the already long list of victims of disease or of murderous savages. Closely following the adventurous mining engineer have come in turn the civil, the mechanical and the electrical engineers, to contribute their labor to the sum of achievement in the advancement of civilization. While the miner has been the pioneer, he recognizes the indispensable co-operation of his confrères and in fraternal congratulation of their common success in this intellectual team-work, through which lost motion is prevented and the highest results are obtained, he rejoices with them in the wise provision of the generous donor of this, our Engineers' Building.

This building becomes a clearing-house of engineering information, facilitating as it does interchange of professional knowledge through the trinity library and through the personal intercourse of engineers of the several specialties. If we avail ourselves, as we undoubtedly shall, of the opportunities thus afforded, we shall contribute in a large measure to the renown of our profession, to the benefit of mankind in general, and to the acknowledgment of our debt to our benefactor, Andrew Carnegie.

The Chairman mentioned the circumstance that Mr. Carnegie's gift included a house for the Engineers' Club, on ground adjacent to that occupied by the home of the Founder Societies, and, alluding to the connection between the two edifices, said: "We have let them in on the ground floor, and by a still higher tie, connecting the two buildings on our ninth story." I am glad to call upon Mr. T. C. Martin, President of the Engineers' Club.

Mr. Martin, in response, read the following verses, which were received with much merriment and applause:

GREETINGS FROM THE ENGINEERS' CLUB.

BY T. C. MARTIN.

To our fellow engineers, who've been looking many years,
  Uptown and down, for a home whose rental wasn't high:
We, members of the Club, which has also felt that rub,
  Bring greetings from our Little House nearby.

With you we share the gift; with yours, our voices lift
  In praises of Carnegie, who aimed our kindred fates to tie.
"A home for you all" is graven on your wall,
  And, deeper, on the cosy Little Club nearby.

Here may brethren dwell in peace; here may your tribes increase;
  Here may the founts of Knowledge ne'er run dry.
But for leisure moments sunny, or refreshing milk and honey,
  Come over to the kindly Little House nearby.

When weary of the jargon of 4 π and of argon,
  And of engineering problems that daily multiply,
Just step across the alley, or by the high bridge sally,
  To the solace of the cheery Little Club nearby.

You are Mining or Electrical, Railway or Mechanical,
  All for truth and fact and data in full cry;
But in the Club we're human, not forgetting there is woman:
  And *all* are welcome in the Little House nearby.

To us within these walls, to all Fair Science calls,
  Onward and upward as our temples pierce the sky!
So to your flow of soul we shall pledge a brimming bowl,
  Comrades! playmates! in the Little Club nearby.

The following societies and institutions were represented by delegates present:

REPRESENTATIVES OF INSTITUTIONS OF LEARNING.

Brown University, Professor William H. Kenerson.

Case School of Applied Science, President Charles S. Howe.

Thomas S. Clarkson Memorial School of Technology, Director C. Aldrich.

University of Cincinnati, President Charles W. Dabney and Dr. Thomas Evans.

Colorado College, President William F. Slocum.

Colorado School of Mines, Arthur R. Townsend.

Columbia University, Frederick A. Goetze, M.Sc., and Professor William H. Burr.

Cornell University, Walter C. Kerr.

University of Georgia, Professor C. M. Strahan.

Haverford College, Professor L. H. Rittenhouse.

Johns Hopkins University, R. Brent Keyser.

University of Illinois, E. W. Goldschmidt.

State College of Kentucky, President James K. Patterson.

Lafayette College, President E. D. Warfield.

Lehigh University, President Henry S. Drinker.

Massachusetts Institute of Technology, Professor R. H. Richards.

University of Michigan, Alfred Noble.

Michigan Agricultural College, Joseph T. Freeman.

United States Military Academy, Captain Richmond P. Davis.

University of Minnesota, Professor Fred. S. Jones.

University of Missouri, Charles Lewis Harrison.

United States Naval Academy, Commander John K. Barton.

College of the City of New York, Professor Albert G. Compton.

New York University, Professor Collins P. Bliss and Professor Charles H. Snow.

Ohio University, President Alston Ellis.

University of Pennsylvania, Professor Henry Wilson Spangler.

Western University of Pennsylvania, Chancellor S. B. McCormick.

Pennsylvania State College.

Polytechnic Institute of Brooklyn, President Fred. W. Atkinson.

Pratt Institute, Director Arthur L. Williston.

Princeton University, Professor Chas. McMillan.

Rensselaer Polytechnic Institute, President P. Ricketts.

Rutgers College, Professor Alfred A. Titsworth.

Stevens Institute of Technology, James E. Denton and Dr. D. S. Jacobus.

St. John's College, President Thomas Fell.

Trinity College, Professor Henry Augustus Perkins.

Tufts College, Professor Gardner C. Anthony.

Union University, Professor Olin H. Landreth.

University of Vermont, Professor W. H. Freedman.

Washington and Lee University, President George H. Denny.

George Washington University, President Charles Willis Needham.

University of Washington, Professor H. K. Benson.

Worcester Polytechnic Institute, Professor L. P. Kinnicutt.

Yale University, President Arthur T. Hadley.

REPRESENTATIVES OF ENGINEERING AND SCIENTIFIC SOCIETIES.

American Ceramic Society, Stanley G. Burt, President.

American Chemical Society, Marston T. Bogert, President.

American Electrochemical Society, Samuel A. Tucker, Chairman, and Dr. E. F. Roeber.

American Foundrymen's Association, Dr. Richard Moldenke, Secretary.

American Gas Institute, Henry L. Doherty.

American Institute of Architects, Cass Gilbert.

American Railway Associations, W. F. Allen, Secretary and Treasurer.

American Railway Master Mechanics' Association, Arthur M. Waitt, past-President.

American Society of Civil Engineers, Nelson P. Lewis.

American Society of Heating and Ventilating Engineers, W. M. Mackay, Secretary.

American Society of Municipal Improvements, George W. Tillson, Secretary.

American Society of Naval Engineers, Commander Albert Moritz.

American Society of Refrigerating Engineers, John E. Starr, President.

American Society for Testing Materials, Professor Edgar Marburg, Secretary-Treasurer.

American Water Works Association, Morris R. Sherrerd.

Association of Railway Superintendents of Bridges and Buildings, Joseph H. Cummin.

Associazione Elettrotecnica Italiana, J. W. Lieb, Jr.

Boston Society of Civil Engineers, Francis W. Dean, Vice-President.

Brooklyn Engineers' Club, C. E. Pollock, President.

Canadian Society of Civil Engineers, W. McLea Walbank.

Concrete Association of New York, Albert Mayer.

Corpo Reale Dellé Miniere, Dr. R. W. Raymond.

Deutsche Chemische Gesellschaft, Dr. C. F. Chandler.

Electrical Contractors' Association, James Hilton.

Empire State Gas and Electric Association, T. R. Beal, Treasurer.

Engineers' Club, T. C. Martin, President.

Engineers' Society of Western New York, Harry B. Alvorson.

Faraday Society, Leon Gaster.

Geological Society of America, Prof. J. J. Stevenson.

Illuminating Engineering Society, Dr. Clayton H. Sharp, President.

Institution of Electrical Engineers, Sir William Preece.

Institution of Mechanical Engineers, Ambrose Swasey.

Institute of Marine Engineers, N. K. McLean.

Iron and Steel Institute, R. A. Hadfield, past-President.

Italian Society of Engineers and Architects, J. W. Lieb, Jr.

Koninklijk Instituut Van Ingenieurs, F. W. Ruhle von Lilienstern ter Meulen.

Master Car Builders' Association, F. W. Brazier.

Municipal Engineers of New York, George S. Rice, President.

National Association of Cotton Manufacturers, Frederick A. Flather.

National Electric Light Association, Arthur Williams, President.

National Fire Protection Association, Charles A. Hexamer, President.

New England Association of Gas Engineers, William McGregor, President.

New England Water Works Association, M. N. Baker, Vice-President.

New York Electrical Society, G. Herbert Condict, President; G. H. Guy, Secretary; H. A. Sinclair, Treasurer.

New York Railroad Club, W. G. Besler, Vice-President.

North of England Institute of Mining and Mechanical Engineers, J. Parke Channing.

Philosophical Society of Washington, G. R. Putnam.

Railway Signal Association, A. H. Rudd, Vice-President.

Society of Automobile Engineers, A. L. Riker, President.

Society of Beaux-Arts Architects, Lloyd Warren, President.

Society of Chemical Industry, T. J. Parker.

Société des Ingenieurs Civils de France, Sorzano de Tejada.

Society of Arts, Sir William Preece.

Society of Naval Architects and Marine Engineers, Stevenson Taylor, Vice-President.

Technical Society of the Pacific Coast, G. W. Dickie, past-President.

Trustees Gas Educational Fund, W. R. Beal, Treasurer.

Verein deutscher Eisenhüttenleute, C. Kirchhoff.

Western Society of Engineers, Professor Morgan Brooks.

The time being manifestly too brief to permit the hearing of written or oral addresses from all these distinguished representatives, the chairman called upon the following few only, who responded in brief but happy messages of congratulation:

Sir William Henry Preece, for the Institution of Electrical Engineers of Great Britain.

Mr. Walter C. Kerr, Trustee of Cornell University, for American universities.

Mr. R. A. Hadfield, past-President of the Iron and Steel Institute, of Great Britain, for that society. (In addition to his cordial and graceful speech, Mr. Hadfield presented an illuminated address from the Iron and Steel Institute.)

Dr. Friedrich Eichler, for the Verband deutscher elektrischer Techniker. (This address was delivered in German.)

Mr. Sorzano de Tejada, for the Society of Civil Engineers of France.

Mr. John F. Wallace, past-President of the American Society of Civil Engineers, who, in the unavoidable absence of President G. H. Benzenberg of that society, presented a cordial communication from the latter.

Dr. Henry Pritchett, President of the Carnegie Foundation, Washington, D. C., and past-President of the Massachusetts Institute of Technology, for the latter institution and technical schools generally.

Mr. Charles Kirchhoff, for the Verein deutscher Eisenhüttenleute. (Mr. Kirchhoff presented an illuminated address.)

Mr. Carl Hering, past-President of the American Institute of Electrical Engineers, for the Société Internationale des Electriciens, of Paris, France.

Mr. Leon Gaster, for the Faraday Society of Great Britain.

Dr. F. R. Archenhold, Director of the Royal Prussian Astronomical Observatory at Treptow, Berlin, presented the greeting of that institution.

Capt. Baxter, U. S. N., President of the Society of Naval Architects and Marine Engineers, spoke for the Associate Societies occupying rooms in the new building.

The Chairman presented a large number of congratulatory letters and telegrams, received from the following:

Lord Kelvin; the Institution of Civil Engineers; the Institution of Mining and Metallurgy; the French National Conservatory of Arts and Sciences; the French International Bureau of Weights and Measures; and many others.

THE JOHN FRITZ MEDAL.

Mr. Charles F. Scott, President of the Board of Award of the John Fritz medal, conferred the medal, in the name of the Board, upon Dr. Alexander Graham Bell, for his invention of the telephone.

Dr. Bell responded in a few hearty words, concluding, amid great applause, with the declaration that this honor was made still more precious to him by the fact that it was bestowed in the presence of the venerable John Fritz himself.

COMMEMORATIVE SECRETARIES' MEDALS.

Dr. A. R. Ledoux, past-President of the American Institute of Mining Engineers and of United Engineering Society, was then called upon to present to Dr. F. R. Hutton, past-Secretary of the American Society of Mechanical Engineers; Mr. Ralph J. Pope, Secretary of the American Institute of Electrical En-

gineers; and Dr. R. W. Raymond, Secretary of the American Institute of Mining Engineers, three gold medals, severally bestowed by the three societies, in recognition of the long service of these officers. Dr. Ledoux prefaced each of these presentations with an appropriate sketch of the career of the recipient.

Dr. Hutton replied for all three, and after a few announcements concerning the technical sessions of the several societies announced for succeeding days, the dedicatory exercises were declared to be complete.

MEMBERSHIP.

The following list comprises the names of those persons elected as members or associates, who accepted election during March and April, 1907:

LIFE MEMBER.

John M. Moubray, Sable Antelope Mine, N. W. Rhodesia, So. Africa.

MEMBERS.

Charles E. Coote,	Launceston, Tasmania.
Carl P. Halter,	Chihuahua, Mex.
Cyril H. James,	Melbourne, Victoria, Australia.
John C. Nicholls,	Chittabalbie, Korea.
William C. Walworth Pearce,	Irvinebank, No. Queensland, Australia.
Leonard C. Stuckey,	Dulcinea Mine, near Copaipo, Chile, So. America.
Harold Turrell,	Lomagundi, Rhodesia, So. Africa.
Henry S. Washington,	Locust, N. J.

NECROLOGY.

The deaths of the following members and associates have been reported to the Secretary's office during March and April, 1907:

Date of Election.	Name.	Date of Decease.
1886.	*Carl W. Bildt,	May 5, 1906.
1897.	*John Blatchford,	August 10, 1906.
1882.	*E. E. Burlingame,	March 20, 1907.
1881.	*William Glenn,	February 16, 1907.
1901.	†William J. Johnston,	April 28, 1907.
1904.	*Frederick W. Mathews,	April 16, 1907.

* Member. † Associate.

CANDIDATES FOR MEMBERSHIP.

The following persons have been proposed for election as members or associates of the Institute during the period, March 16 to May 1, 1907. Their names are published for the information of members and associates, from whom the Committee on Membership earnestly invites confidential communications, favorable or unfavorable, concerning these candidates. A sufficient period (varying in the discretion of the Committee, according to the residence of the candidate) will be allowed for the reception of such communications, before any action upon these names by the Committee. After the lapse of this period, the Committee will recommend action by the Council, which has the power of final election. The names of candidates were formerly published in the various circulars of the Institute, issued from time to time to the members. Hereafter, they will appear regularly in the *Bi-Monthly Bulletin*, each number of which will contain the names received since the issue of the preceding *Bulletin*.

LIFE MEMBER.

Millard King Shaler, ... Washington, D. C.

MEMBERS.

Samuel J. Alderman, ... Benton, Cal.
John Andrew Allen, ... Cleveland, So. Africa.
Frank Harold Brown, ... Coppermount, Alaska.
Frank Melville Chambers, ... Tonopah, Nev.
Temple Chapman, ... Webb City, Mo.
John Adams Church, Jr., ... Guanajuato, Mex.
Raymond Benson Crowell, ... Carson City, Nev.
Floyd E. Cunnyngham, ... Bristol, Va.-Tenn.
Jack Cussons, ... Mineral, Va.
A. C. de Jongh, ... Nijmegen, Holland.
Emil Edward Dieffenbach, ... Newark, N. J.
George Miller Dyott, ... Pittsburg, Pa.
George Robert Deming Easley, ... Mackay, Idaho.
Adrian Davenport Eatherly, ... Chilton, W. Va.
Edwin E. Ellis, ... Duluth, Minn.
George Watkin Evans, ... Pullman, Wash.
Aubrey Fellows, ... Rolla, Mo.
Norman Richard Fisher, ... New York, N. Y.
James H. Gray, ... New York, N. Y.

Robert Watson Hadden,	Albuquerque, N. M.
John S. Hamman,	Rhyolite, Nev.
Kiohey Hasegawa,	Bisbee, Ariz.
Dr. Paul L. T. Héroult,	New York, N. Y.
Preston King Horner,	Ely, Nev.
James Humes,	Basin, Mont.
J. M. Humphrey,	Centralia, Pa.
Alfred Kimber,	New York, N. Y.
F. Forster Kip,	Teniosachic, Chih., Mex.
Berth. Kopelowitz,	Nigel, Transvaal, So. Africa.
Julius Kruttschmitt, Jr.,	Chicago, Ill.
James Lea,	Johannesburg, So. Africa.
Malcolm Docker Lincoln,	Albuquerque, N. M.
Alexander Campbell Smith McLeod,	Daylesford, Victoria, Australia.
Ronald Van Auken Mills,	San Pedro, N. M.
Maxwell Claypoole Milton,	Bisbee, Ariz.
Roy Webb Moore,	Cumpas, Sonora, Mex.
McHenry Mosier,	Bisbee, Ariz.
John William Oliphint,	Teniosachic, Chih., Mex.
E. A. Prentis, Jr.,	Lima, Peru.
John N. Reese,	Pulaski, Va.
Edward F. Schaefer,	New York, N. Y.
Rudolf von Seyfried,	Newark, N. J.
Frederic Henry Sexton,	Halifax, N. S., Can.
S. F. Shaw,	Sta. Barbara, Chih., Mex.
Waldo Sheldon,	New Haven, Conn.
Alfred Comstock Sieboth,	Florance, Ariz.
Trevor B. Simon,	Columbus, O.
William Joseph Sinn,	New Haven, Conn.
Paul Xaver Stoffel,	Mapimi, Durango, Mex.
William S. Sultan,	Globe, Ariz.
Henry N. Thomson,	Anaconda, Mont.
Paul Britten Tracy,	Bingham Canyon, Utah.
Atherton Blight Wadleigh,	Cananea, Sonora, Mex.
Clement L. Webster,	Charles City, Iowa.
Edwin Perkins Williams,	South Chicago, Ill.

ASSOCIATES.

Henry F. Blackwell,	Brooklyn, N. Y.
John H. Leavell,	Boston, Mass.

CHANGE OF STATUS FROM ASSOCIATE TO MEMBER.

Walter A. Emeis,	Shullsburg, Wis.
Marcus I. Goldman,	New York, N. Y.
Enrique E. Laroza,	Brussels, Belgium.

CHANGE OF ADDRESS OF MEMBERS.

The following changes of address of members have been received at the Secretary's office during the period of March 15 to May 1, 1907. This list, together with the list of changes of address published in *Bi-Monthly Bulletin*, No. 14, March, 1907, supplements the annual list of members corrected to Jan. 1, 1907, and brings it up to the date of May 1, 1907. The names of members who have accepted election during March and April, 1907 (new members), are printed in *italics*.

The large number of changes of address since Jan. 1, 1907, shows the importance of publishing these changes as frequently as possible, and the *Bi-Monthly Bulletin* has been selected as the means to present this information to the members of the Institute. By the simple method of cutting out these names and addresses and pasting them directly over the corresponding names in the annual list of members, the record can be kept practically up to date, and the value of the list correspondingly increased. For this purpose the changes of address have been printed only on one side of the page. The names of new members, being in italics, are readily distinguished from the others, and can be pasted in approximate alphabetical order on the margins of the pages.

AARONS, J. BOYD.........The Vivian G. M. Co., Ltd., Harris, Western Australia.
ABBOTT, A. A..........Morococha, Peru, So. Amer.
ABBOTT, JAMES W..........Pioche, Lincoln Co., Nev.
ADAMS, RALPH E., Care Minas Tecolotes y Anexas, Santa Barbara, Chih., Mexico.
ADAMS, T. J..........Rahway, N. J.
ALLEN, FREDERICK E..........366 Center St., Bloomsburg, Pa.
ANDERSON, AXEL E., E. I. Du Pont De Nemours Powder Co.,
P. O. Drawer 1001, Wilmington, Del.
ARMSTRONG, JOHN O., Genl. Mine Mgr., Great Cobar, Ltd.,
Cobar, N. S. W., Australia.
ARNOLD, CHARLES E. LE N..........Kellogg, Idaho.
ASHMORE, G. PERCY..........109 Lansdowne Place, Hove, Sussex, England.
AUSTIN, KENNETH, Cons. Engr., Robinson Gold Mining Co., Ltd.,
P. O. Box 2154, Johannesburg, Transvaal, So. Africa.
BAILEY, J. TROWBRIDGE..........2 Rector St., New York, N. Y.
BARBER, GEORGE M..........42 Clapham Road, Bedford, England.

BATCHELDER, JOSEPH F..54 First St., Portland, Ore.
BEARDSLEY, GEORGE F...............1315 E. 14th St., Fruitvale, Alameda Co., Cal.
BELL, FRANK R..118 W. 5th St., Joplin, Mo.
BELL, STANISLAUS C. N......General Post Office, Brisbane, Queensland, Australia.
BENJAMIN, EDWARD H...................................903 Linden St., Oakland, Cal.
BOSCO, FRANCIS W.............................1834 South Sherman Ave., Denver, Colo.
BOSQUI, FRANCIS L...Studio Bldg., Berkeley, Cal.
BOURDARIAT, ALEXANDER J........................Tananarire, Madagascar, via Paris.
BRADLEY, OLIVER U...Box 23, Wonder, Nev.
BRADY, LEON H., Min. Engr., Supt. Mina Granadena,
Granadena Mining Co., Santa Barbara, Chih., Mexico.
BROUD, WALLACE.....................U. S. Postal Agency, Box 926, Shanghai, China.
BROCKUNIER, S. H..525 Greenwich St., Reading, Pa.
BROPHY, JAMES...Bear Creek, Carbon Co., Mont.
BROWN, WILLIAM F..Address wanted.
BURHANS, HARRY H..Address wanted.
BURRELL, FREDERICK P........................1 Progress Flats, Salt Lake City, Utah.
BURROWS, CHARLES W......Albert Ave., Chatswood, Sydney, N. S. W., Australia.
CALDERWOOD, JAMES M..........189 Exploration Bldg., Johannesburg, So. Africa.
CARNEY, HUGH J...Ouray, Colo.
CARR, HENRY C., Mgr., Nevada Consol. Min. & Mill. Co., Box 111, Wadsworth, Nev.
CARTER, HENRY M....................................486 W. 4th Ave., Columbus, Ohio.
CHASE, FRANK D.........National Metal Co., Apartado 71 B, Mexico City, Mexico.
CLEMENT, HARRISON E.......................312 Dooly Block, Salt Lake City, Utah.
CLIMO, JAMES C..........................Care Mann, Whittemore Co., Rhyolite, Nev.
CONLEY, OWEN J...18 Broadway, New York, N. Y.
CONNER, ELI T., Genl. Mgr..........New River Collieries Co., Thurmond, W. Va.
COOMBS, HARALD L...Globe, Ariz.
COOPER, JOHN..Mazapil, Zac., Mexico.
Coote, Charles E., Min. Engr., Stock Exchange Bldgs., Launceston, Tasmania. * '06
COSGRO, JOHN P., Mech. Supt...American Smelters Securities Co., Flat River, Mo.
CREMER, FELIX, Guanajuato Amalgamated Gold Mines Co.,
La Luz, Guanajuato, Mexico.
CREWE, LEONARD C...................................The Goshen Iron Co., Goshen, Va.
CROCKER, A. L..............314 Natl. Bank of Commerce Bldg., Minneapolis, Minn.
CUMMINGS, W. N., Min. Engr...............................422 Roe Bldg., St. Louis, Mo.
DE SOLLAR, TENNY C., Mine Engr. and Met.,
Consolidated M. M. & S. Co., Eldora, Colo.
DIXON, ALEXANDER G..........Care Carlos Moser, Cuatro Cienegas, Coah., Mexico.
DIXON, JAMES T..............."Melrose," St. James Road, Sutton, Surrey, England.
DONEY, DE WITT C..Address wanted.
DORR, JOHN VAN N ....204 Bank Block, Denver, Colo.
DOUGLASS, ROSS E..........................Choix, Sinaloa, Mexico, via Nogales, Ariz.
DOWLING, WALFORD R......P. O. Box 143, Knights Deep,
Germiston, Transvaal, So. Africa.
EDWARDS, ROBERT L............Nevada Golden Eagle Min. Co., Winnemucca, Nev.
EKBERG, BENJAMIN P...Address wanted.
ELLAM, A. SPENCER, Care Mexican Concessions, Ltd.,
138 Leadenhall St., London, E. C., England.
EMEIS, WALTER A., Min. Engr...Secty., The Iowa Mining Co., Shullsburg, Wis.
EMERSON, EDWARD H.........................El Cobre Mines, Santiago de Cuba, Cuba.
EMLAW, HARLAN S..Grand Haven, Mich.

FAY, ALBERT H..Instructed to hold all mail.
FINDLAY, JAMES..Address wanted.
FINLAY, JAMES R...2 Rector St., New York, N. Y.
FITCH, MAX B...711 Brown St., El Paso, Texas.
FITCH, WALTER..Calumet, Mich.
FLYNN, F. N..La Rose Mine, Cobalt, Ont., Canada.
FULLER, JAMES W.....Prest., Lehigh Car Wheel & Axle Works, Catasauqua, Pa.
GARREY, GEORGE H., Geol. Dept., Am. Smelting & Refining Co.,
71 Broadway, New York, N. Y.
GIBB, ALLAN, Min. Engr...........359 Queen St., Brisbane, Queensland, Australia.
GILCHRIST, PERCY C., Flat 22, 16 St. James Place, Pall Mall,
London, S. W., England.
GOULD, HERBERT J., Min. Engr. and Met., Albert St., Edgecliff,
Sydney, N. S. W., Australia.
Goupilliere, Haton de la, Inspecteur Général des Mines,
56 Rue de Vaugirard, Paris (VIe arrond), France.
GRAYSON, L. W..............................414 Collins St., Melbourne, Vic., Australia.
GREENE, FRED T............................220 Great Northern Bldg., St. Paul, Minn.
GRIFFIN, FITZ ROY N., Care Thomas Cook & Son, 245 Broadway, New York, N. Y.
GUNTLEY, EDWARD A., Min. Engr..........3914 South Grand Ave., St. Louis, Mo.
Halter, Carl P., Mine Mgr....................Apartado 52, Chihuahua, Mexico. * '06
HAMMON, W. P., Genl. Mgr., Oroville Dredging, Ltd.,
and Feather River Exploration Consolidated, Oroville, Cal.
HAGUE, WILLIAM..P. O. Box 296, Douglas, Ariz.
HAHN, O. H., Min. and Met. Engr..................Schillerstrasse 6, Iena, Germany.
HANCKEL, ROBERT S., Civ. Engr. and Surveyor,
Casilla 362, San José, Costa Rica, Cent. Amer.
HAUBER, MATHIAS, JR.........Cia Minera de Penoles, Mapimi, Durango, Mexico.
HECK, ELMER C..........................Care The El Paso Smltg. Wks., El Paso, Tex.
HERMAN, HYMAN..................Ailsa, Glen Ena Road, St. Kilda, Vic., Australia.
HERRICK, RAY L., *Mines and Minerals*..............1 Ferguson Bldg., Denver, Colo.
HEYWOOD, WILLIAM A.......................The Spassky Works, Akmolinsk, Siberia.
HINDSHAW, HENRY H.................................29 Broadway, New York, N. Y.
HOFFMANN, JOHN I., United S. African Asso., Ltd.,
Brown's Bldgs., Loveday St., Johannesburg, So. Africa.
HOLLISTER, JOHN J.............Guanajuato Development Co., Guanajuato, Mexico.
HOVLAND, H. B...403 Lonsdale Bldg., Duluth, Minn.
INGERSOLL, J. W..Address wanted.
JAMES, CYRIL HAUGHTON, Min. Engr., Bewick-Moreing & Co.,
Equitable Bldg., Melbourne, Vic., Australia.
JOHNSON, ALEXANDER T..Wonder, Nev.
JOHNSON, GUY R., Vice-Prest. and Genl. Mgr., Alabama Consolidated
Coal & Iron Co., 825 1st Natl. Bank Bldg., Birmingham, Ala.
JOHNSON, PAUL...1517 Boylston Ave., Seattle, Wash.
JOHNSON, RALPH I....................................3233 2d Ave. S, Minneapolis, Minn.
JONES, HENRY E., The Rhodesia Exploration & Development Co., Ltd.,
P. O. Box 203, Bulawayo, Rhodesia, So. Africa.
JONES, OWEN, Care Senor J. E. Harmsen, Sociedad Esplotadora
de Caylloma, Areguipa, Peru, So. Amer.
JOST, FRED..Address wanted.
KAEDING, CHARLES D., Asst. Genl. Mgr., Oriental Consol. Mining Co.,
Munsan, Korea.

KELLER, DR. EDWARD.............................P. O. Box 363, Perth Amboy, N. J.
KNEPPER, EARL H..Address wanted.
KONDO, R........................ ....1 Chome Yayesucho, Kojimachiku, Tokio, Japan.
LAROZA, ENRIQUE E., Min. and Elec. Engr.,
Care Mr. J. Melckebeke, Casilla 12, Lima, Peru, So. Amer.
LENGLE, E. FLEMING...............................110 W. 57th St., New York, N. Y.
LEWIS, J. VOLNEY..............................Rutgers College, New Brunswick, N. J.
LIGHT, HERBERT H...2129 Kittredge, Berkeley, Cal.
LONGMAID, FRANK.............. ....Boeme, Tex.
MCCAFFERY, RICHARD S..........................Herald Bldg., Salt Lake City, Utah.
MCCORD, WILLIAM H., The Providencia Min. & Mill. Co.,
Apartado 1355, Mexico City, Mexico.
MCCORMICK, EDWARD, Supt., Minas Zaragoza y Anexas,
Apartado 103, Monterey, N. L., Mexico.
MACDONALD, CHARLES...5 Nassau St., New York, N. Y.
MCILVAIN, EDWARD, Robins Conveying Belt Co.,
Park Row Bldg., New York, N. Y.
MCKINLAY, WM. B..................................519 W. 152d St., New York, N. Y.
MACKAY, ANGUS......................Alaska Metals Mining Co., Coppermount, Alaska.
MACKEY, PERRY D., Genl. Mgr.............Western Iron & Steel Co., Denver, Colo.
MATTES, W. F...................................514 Board of Trade Bldg., Scranton, Pa.
MAUNEY, A. C.. .Whitney, N. C.
MILDON, R. B.........................Duquesne Min. & Reduct. Co., Duquesne, Ariz.
MILLER, CHARLES W...Box 694, Boise, Idaho.
MILLER, JOSEPH, Mine Supt., Tasmanian Copper Co., Ltd.,
Leigh Creek, So. Australia.
MITCHELL-ROBERTS, J. F...Humboldt, Ariz.
MOORE, REDICK R................................Apartado 103, Oaxaca, Oax., Mexico.
MORRIS, REV. RICHARD J.........................509 Lincoln Drive, Germantown, Pa.
MOSES, HORACE, Care Highland Boy Mine, Utah Consol. Min. Co., Bingham, Utah.
Moubray, John M., Min. Engr., Sable Antelope Mine,
N. W. Rhodesia, So. Africa. * '06
MUNRO, CHARLES H..Dutch Flat, Placer Co., Cal.
MURPHY, THOMAS D..........................69 Avenida Madrid, Mexico City, Mexico.
NEWCOMB, CLIVE S., Care Dolores Mines Co., Estacion San Isidro,
Dto, Guerrero, Chih., Mexico.
NEWMAN, BRUNO..................................Apartado 90, Aguascalientes, Mexico.
NOON, EDWARD E..Nogales, Ariz.
Pearce, William C. Walworth, Min. and Met. Engr., Irvinebank,
North Queensland, Australia. * '06
PERIN, CHARLES P...2 Rector St., New York, N. Y.
PETERS, RICHARD, JR........................Birmingham Iron Co., Birmingham, Ala.
PLATER, JOHN E...707 W. 28th St., Los Angeles, Cal.
PLUMB, CARLTON H., Care Plumb & Sansom, Civ. and Min. Engrs.,
10 & 11 McKinley Bldg., Joplin, Mo.
POINDEXTER, C. L........Care J. G. Dailey, Apartado 84, Torreon, Coah., Mexico.
POMEROY, ERNEST Y.....Care Black Mt. Mining Co., Magdalena, Sonora, Mexico.
PURDY, HENRY T., Mech. and Elec. Engr........San José, Costa Rica, Cent. Amer.
RALEIGH, JOSEPH R., Branch Mgr., Irvinebank Mining Co.,
Irvinebank, Queensland, Australia.
RAYMOND, STEPHEN S...................... ....Address wanted.
READ, THOMAS T., Prof. of Min. and Met., Colorado College,
Colorado Springs, Colo.

REQUA, M. L..1611 Franklin St., San Francisco, Cal.
RICKARD, ARTHUR J......................10 Treyeu Road, Truro, Cornwall, England.
RING, AMBROSE E..Farmington, St. Francis Co., Mo.
ROBERTSON, HORACE P..........Zona Benito Juarez, La Honda, Zacatecas, Mexico.
ROESLER, AUGUST..Address wanted.
RUMBOLD, WILLIAM R.........Andes Tin Co., Concordia Mine, Bolivia, So. Amer.
SABIN, JAY H................ ....6611 Kimbark Ave., Chicago, Ill.
SAHLIN, AXEL, Engr., Julian Kennedy, Sahlin & Co.,
52 Rue du Congrès, Bruxelles, Belgium.
SCHADER, CARL F...................................416 Currier Bldg., Los Angeles, Cal.
SCHIERTZ, FERDINAND A., Prof of Met. and Chem.,
Montana State School of Mines, Butte, Mont.
SCOVIL, HENRY H..................................1380 Old Colony Bldg., Chicago, Ill.
SHARPLEY, HAROLD.................................. ....Address wanted.
SEAMON. H. J..Catasauqua, Pa.
SHAW, RICHARD C., Genl. Mgr., Montezuma Mine, Inc.,
Montezuma, Costa Rica, Cent. Amer.
SHOCKLEY, W. H..P. O. Box 511, Tonopah, Nev.
SHORT, FRANK R...Address wanted.
SHERRICK, ADAM T.............................Bear Creek Coal Co., Bear Creek, Mont.
SIMPSON, GILBERT C........................Am. Smg. & Refg. Co., Chihuahua, Mexico.
SLOAT, FRANK...Valdosta, Ga.
SMITH, A. PARKER..2 Rector St., New York, N. Y.
SMITH, CHARLES ALFRED..502 Main St., Oconto, Wis.
SMITH, E. PERCY, Supt., Minas Dolores y Anexas,
Matehuala, San Luis Potosi, Mexico.
SMITH, NOAH B..6 North 50th St., Philadelphia, Pa.
SMITH, S. RODMAN...Address wanted.
SPIES, ALBERT, Editor *The Electrical Record*.....123 Liberty St., New York, N. Y.
STANFORD, H. R.....Care Bureau Yards & Docks, Navy Dept., Washington, D. C.
STANLEY, JAMES, Asst. Mgr., Kluchi Gold Mines, Ltd.,
Translaickal, Sabolinaya, Kluchi Mine, Siberia.
STARR, CHARLES C..............................Patagonia Mining Co., Patagonia, Ariz.
STEELE, THOMAS E...Wilcox, Ariz.
STEWART, ALEXANDER...Salisbury House, London Wall, London, E. C., England.
STEWART, HOWARD R.............................Imperial Copper Co., Silverbell, Ariz.
STOCKETT, ALFRED W.....................P. O. Box, 6051, Johannesburg, So. Africa.
SUMMERHAYES, MAURICE W............28 Elgin Park, Redlands, Bristol, England.
SUTHERLAND, LUTHER A..Address wanted.
TAKAGI, KIRCHIRO, Genl. Mgr, The Tagawa Collieries,
Mitsui Mining Co., Buzen, Japan.
THOMAS, CHESTER A., Resident Manager, Yukon Consolidated
Gold Fields Co., Dawson, Y. T., Canada.
TOLL, R. H., Prest. and Mgr., Lost Lillie Mining & Leasing Co.,
Cripple Creek, Colo.
Tolman, Cyrus F., Jr..................................521 East 3d St., Tucson, Ariz. '06
TOMBO, CARL...Box 30, Station J, New York, N. Y.
TRERISE, JOSIAH H.........................P. O. Box 2086, Johannesburg, So. Africa.
TURNER, SCOTT, Asst. Editor *Mining and Scientific Press*.........San Francisco, Cal.
TURRELL, HAROLD, Mine Mgr., West Rhodesian Banket Co., Ltd.,
Care Eldorado Mine, Lomagundi, Rhodesia, So. Africa. * '06
TYLER, NAT., JR.................................114-118 Liberty St., New York, N. Y.

VALENTINE, CHARLES F., Min. Engr., Surveyor,
Cairns, North Queensland, Australia.
VAN ZWALENVENBURG, A.............................505 Pearl St., New York, N. Y.
WADSWORTH, M. E., Dean, Prof. of Min. and Geol., School of
Mines and Met., Penna. State College, State College, Pa.
WALKER, ARTHUR L., American Smelters Securities Co.,
71 Broadway, New York, N. Y.
WARN, JOHN E., Supt., North Mount Boppy Mine,
Cambellego, N. S. W., Australia.
Washington, Henry S., Geologist and Petrographer...............Locust, N. J. * '07
WATSON, CHARLES E...Care Elks Club, Oakland, Cal.
WEAVER, ISAAC S..... ....426 Ridge Bldg., Kansas City, Mo.
WEBSTER, PAUL W., Asst. Genl. Mgr.......W. H. Treadwell & Co., Lebanon, Pa.
WEPFER, G. W...122 Bartlett St., San Francisco, Cal.
WHITWORTH, SAMUEL, The Australian Metal Co., Ltd.,
P. O. Box 36, Broken Hill, N. S. W., Australia.
WILKINSON, DAVID, Care S. Neumann & Co., Salisbury House,
London Wall, London, E. C., England.
WILLIAMS, ROBERT Y..Moundsville, W. Va.
WINES, JERRY M...P. O. Box 535, San Antonio, Texas.
WOOD, GEORGE R..1207-8 Park Bldg., Pittsburg, Pa.
YOUNG, WAYLAND H...403 Adams St., Oakland, Cal.

ADDRESS WANTED.

Brown, William F.
Bruce, Thos. C.
Burhans, Harry H.
Doney, De Witt C.
Ekberg, Benjamin P.
Findlay, James.
Ingersoll, J. W.
Jost, Fred.
Knepper, Earl H.
Mannheim, E. A.
Patterson, Alfred B.
Raymond, Stephen S.
Reisinger, Paul.
Rilly, Paul de.
Roesler, August.
Sharpley, Harold.
Short, Frank R.
Smith, S. Rodman.
Stevenson, Robert.
Sutherland, Luther A.
Thomas, George W.

SECTION II.

TECHNICAL PAPERS AND DISCUSSIONS.

[The American Institute of Mining Engineers does not assume responsibility for any statement of fact or opinion advanced in its papers or discussions.]

A detailed list of the papers contained in this section is given in the Table of Contents, pages i and ii.

Comments or criticisms upon all papers given in this section, whether private corrections of typographical or other errors or communications for publication as "Discussions," or independent papers on the same or a related subject, are earnestly invited.

ERRATA.

Corrections to *Bi-Monthly Bulletin*, No. 14, March, 1907.

Page.

302, line 4. For "two years" read "seventeen months."

303. On the map, Fig. 2, the U. S. M. M. No. 1 is incorrectly shown. The circle should be to the right of the lettering; the mineral monument stands on a bold ridge of limestone, but is shown in the granite area.

328, line 13. For "reigon" read "region."

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Search for the Causes of Injury to Vegetation in an Urban Villa Near a Large Industrial Establishment.*

BY PERSIFOR FRAZER, PHILADELPHIA, PA.

(New York Meeting, April, 1907.)

INTRODUCTION.

For various reasons I have not specified the locality where the research indicated in the following pages was undertaken. It will suffice to say that it was on the grounds of a villa once remote from, but now completely surrounded by, its neighboring city, and in close proximity to an industrial establishment of great extent and importance manufacturing many kinds of steel articles and employing upwards of thirty chimney-stacks for power and process work.

The problem was to discover the cause or causes of the mortality to trees and plants on the place, and to trace these causes to their origin.

Before undertaking this experimental work, the bibliography accompanying this paper was compiled and studied.

It appears from an examination of the careful scientific work performed by the ablest French, German, and English chemists during the last 25 years that they are unanimous in assigning the principal—in fact, the overwhelmingly predominant—cause of the destruction of vegetation to sulphur oxides, resulting either from direct oxidation of sulphur in oil of vitriol works, etc., or from the oxidation of the sulphur from the minerals associated with commercial coal.

Schröder and Schertel showed in 1884 that the sulphates deposited upon the leaves are not injurious to the plants; and Freytag proved that free sulphuric acid could not be found

* SECRETARY'S NOTE.—The manuscript of this paper was received in June, 1906, and the paper was read by title at the London Meeting, July, 1906. But since there was no opportunity at that meeting to present its contents, even in oral abstract, the paper was transferred, with the author's consent, to the New York Meeting. The foregoing statement will fix its real date (so far as questions of priority are concerned) in June, 1906.

in the soil because the atmospheric water carried away all which did not immediately combine with its basic constituents.

The sulphates which accumulate in the ground are highly favorable to plant-growth—especially lime sulphate, which is partly carried into the tissues of the plants and increases the percentage of sulphur in the ash of the leaves analyzed.

The old method of determining the cause of injury by analyzing the leaves of plants is open to the objection that the sulphuric oxide detected is due partly to a harmful and partly to a harmless source, while the amount to be ascribed to each is indeterminable.

In the investigation here described, which I pursued for six months, I was assisted by my son, Mr. John Frazer, Instructor in the Chemical Department of the University of Pennsylvania.

I concluded to follow the old established method pursued by Freytag, Schröder, Schertel, Reuss, Haselhoff and Lindau, Haywood of the Agricultural Department at Washington, and many others, which consists in analyzing the plant and the soil of the region of injury, and for comparison, those of a region remote from the injurious action, and deducting the amount of sulphuric oxide in the latter from that found in the former, to ascertain the excess due to the acid-producing works. But in addition to this method, by means of apparatus devised for the purpose, I measured the amount of sulphur oxides in the air coming from the works, and compared it with that coming from other directions. This method established the source of the injury directly instead of indirectly; yet in spite of its obvious advantages it seems never heretofore to have been employed except by Prof. Mabery in 1894. This is strange, the more so that in the fifth chapter of Haselhoff and Lindau's classical work it is stated that "another way to prove the effect of acid smoke-gases on plants is the demonstration of the smoke-gases with reference to their injurious constituents in the air of the locality of plant-injury in question." But the method thus mentioned was that employed by Braconnot and Simonin near Nancy in 1848, and consisted simply in the use of litmus-paper placed at different distances and in different directions from the place of emission of the furnace-gases. By that method it is possible to ascertain only that there are acid vapors of some kind in the

air, but it does not prove, even qualitatively, the presence of sulphur oxides, the predominating influence of which in the destruction of vegetation was not known at that time.

It is worth while in this connection to quote the conclusions reached by Haselhoff and Lindau as the result of their own exhaustive researches and those of all of their predecessors up to 1903, which are found on page 143 of their book, at the end of the general treatment of the subject; and may be translated and epitomized as follows:

1. Even by strong and repeated additions of sulphurous and sulphuric oxide to soils no essential increase of the sulphur-content is effected; no change of the constitution of the soil takes place; and therefore injury to the plants through the soil is out of the question.

2. Direct action of free sulphurous or sulphuric oxide on the roots of plants is improbable. Should an increase of sulphates occur through the action of smoke-gases on the soil, this would have no injurious effect upon the growth of plants, and may be excluded from consideration.

3. An injurious effect on plants can only occur when the acid gases come into direct contact with the leaf-organs of plants. By injury of plants through SO_2 the content of SO_3 in the plant is always increased; but as this occurs also when the content of sulphates in the soil increases, the observation by itself cannot prove injury through acid gases. The peculiar conditions of each place must be considered.

4. The susceptibility of different plants to sulphurous and sulphuric oxides is different; and even the same plants show different degrees of susceptibility according to their location.

5. Long exposure to even so small a quantity as one millionth of sulphurous acid has been found injurious.

Schröder considers this acid less, Freytag more, injurious to vegetation than sulphuric acid.

6. The various quantities of sulphuric acid collected from the same surface of leaf of two different plants under approximately the same circumstances will not of themselves afford a measure of the injury done to the whole organism of the plants; on the contrary, the specific peculiarities of the several plants must be taken into account and submitted to proof.

7. The cracks in the leaf-organs have nothing to do with the absorption of sulphurous acid. The gas is not absorbed through these cracks but by the entire leaf-surface, and the amount of absorption depends upon the peculiar organization of the leaf.

8. The effect of the absorption of sulphurous acid is to disturb the circulation of water. This appears in an increased extrusion of water, and results in the drying of the leaves.

9. The absorption of sulphurous acid, and consequent disturbance of the circulation of water in the plant, is, for the same proportion of sulphurous acid to the air, greater for a given time with light, high temperature and dry air, than with darkness, low temperature and moist air.

The sulphurous acid and acid smoke-gases in general are more injurious by day than by night.

10. Morphologically, the effect of the sulphurous acid is shown by the formation of spots on the leaves, the death of the leaves and twigs, the retardation of the rings of growth, and finally the destruction of the plant.

11. In the interior of the cell plasmolysis is induced; the grains of chlorophyll are destroyed, and finally form with the plasma and other materials a brown amorphous mass. At the same time, in most cases, especially if the injury has been gradual, tannin separates out, as can be detected by brown or black nodules in the cells.

12. The mode of action of the sulphurous acid is to be conceived as a disturbance of the life of the plasma in the cell. It probably acts as sulphuric acid produced through the oxidation of sulphurous acid by the oxygen of the assimilating chorophyll grains in the presence of water from the cell-sap.

13. By the continuous action of rain or water from other sources, the sulphuric acid of the dead leaf-organs which has been taken from the air may be again eliminated. In conifers, and probably other plants, of which the organs are gummy or waxy, the sulphurous or sulphuric acid taken from smoke-gases is not further neutralized in the mass, so that the recognition of smoke-injury is impossible.

14. No absolutely sure botanical means exists of recognizing the injuries by sulphurous acid, but it is possible, only through the complex of outward and interior injuries, to conclude their presence. The surest proof is the chemical determination of sulphuric acid.

I. Journal of the Investigation.

1905.

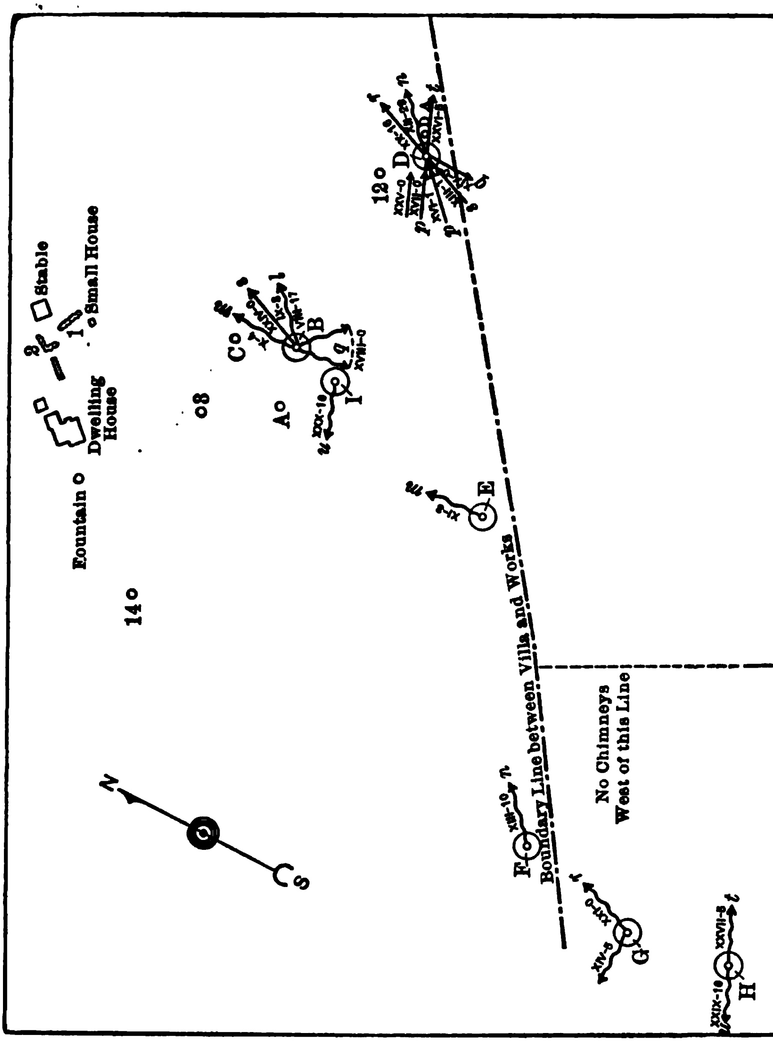
February 24.—There were brought to me some papers and a blackened cloth relating to the case of the smoke-nuisance. I began at once a series of experiments with the object of ascertaining whether the injuries complained of were actual; if so, to what substances they were due; and what was the source of the injurious substances.

The cloth originally had been white; but by exposure for a few days to the air on the lawn it had become changed to a dark gray.

March 28.—The weather being for the first time favorable for observation, I removed the heads of three flour-barrels, and placed on an expansible hoop, in the middle of each, a diaphragm of cloth saturated with alkaline carbonates. The cloth had been previously tested and proved to contain no sulphur or sulphates, and the weight of its ash for a given area had been determined. The barrels with their cloth diaphragms were then placed at points A, B and C on the map, Fig. 1, the axes of the barrels pointing in the direction of the industrial works, which were suspected of contaminating the air. The cloths were thus exposed for about four days.

March 31.—The cloths at A, B and C, Fig. 1, were removed and replaced by others.

April 16 to 18.—I visited Pike county with Mr. John Frazer



Scale, 1 in. = 516 ft.

Fig. 1.—Sketch-Map, Showing General Situation and Points of Observation.

to obtain from a region free from coal-smoke specimens of vegetation similar to that under examination.

April 22.—The cloths exposed March 31 were removed and replaced by others.

Examination showed that in every case the cloths had taken up from the atmosphere a large percentage of their respective

weights, varying from 6.06 (A, second experiment) to 10.85 (A, first experiment) per cent. of SO_3. In other words, a cloth about 20 cm. square absorbed, during four days' exposure to the air, 10.85 per cent. of its own weight of SO_3 from the atmosphere.

These experiments proved conclusively that there existed in the air, at least at intervals, during the period from March 28 to March 31, large quantities of the poison which was respon-

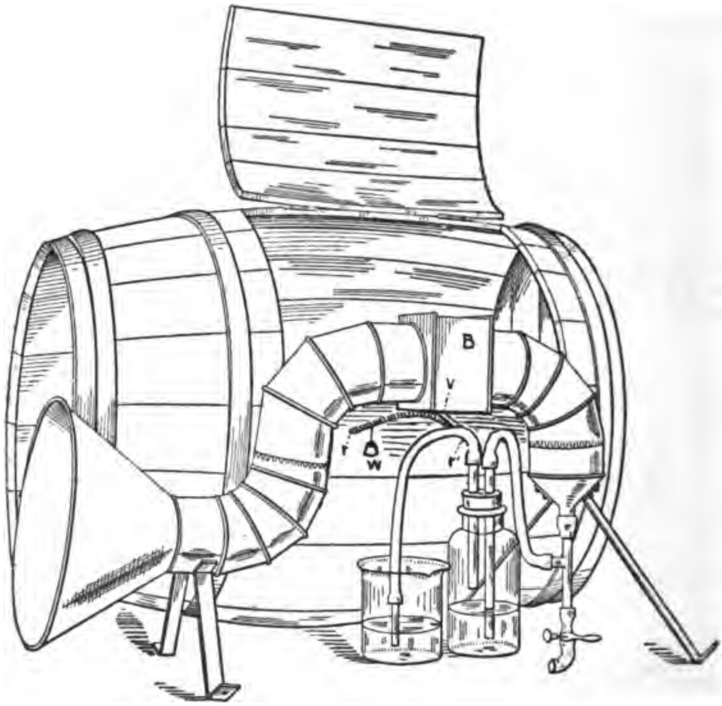


FIG. 2.—AUTOMATIC AIR-SELECTER.

B, square box uniting two systems of jointed pipes;
v, valve in the bottom of the box; held in place by
r, rod of stiff wire attached to the wooden valve, and pressing it into place by means of
w, a weight suspended from the free end of r.

sible for the injury and death of the plants. The results will be found in Table I.

The automatic apparatus for examining air coming from a given direction was set up at A, in a barrel arranged for the purpose.

Fig. 2 is a view of this apparatus. It consists of a funnel-shaped mouth, of which the angle between the sides of the

cone-frustum and the base is such that currents of air which are not approximately in the direction of the axis of the jointed pipe immediately behind it cannot exert pressure enough to pass through the solution contained in a Wolf-necked bottle at the posterior extremity of the conducting-pipe. Consequently, by setting the apparatus in such a position that lines parallel to the axis of the barrel passed through some part of the works suspected of emitting the noxious gases, it was rendered certain that no air from other directions could enter the solution.

The jointed pipe was curved upwards and again downwards to prevent rain from entering the fixing-flask. It was furnished with a square box in the middle or highest part of the curve, in which was a hinged safety-valve connected with a wire lever, to prevent a too-strong wind from scattering the solution and breaking the apparatus. A very slight weight was sufficient to keep the valve closed while the air passed through the solution.

From the second tube of the Wolf flask a glass tube connected by a rubber tube dipped into a beaker containing a little water, to seal the fixing-flask from the air.

The whole apparatus was secured by iron bands and clamps screwed to the inner sides of an ordinary flour-barrel, into the upper half of which a door had been cut and hinged for the purpose of permitting free manipulation.

A solution of alkaline carbonate was placed in the Wolf flask, which, when the connections were made, was left for a varying number of days to receive the sulphur oxides carried by the wind from the direction of the works.

The records of the results of these experiments will be found in Table I. As the latter were qualitative, they were substituted later by quantitative experiments in which a known volume of air from the pipe was pumped through the solution.

April 24.—The automatic air-selecter was moved from A to B, and the air-valve was closed by means of a light weight.

May 1.—The contents of the fixing-flask at B were removed and the bottle was refilled with alkaline solution. The solution removed contained 0.0125 g. of SO_3. For future quantitative measurements, a small force-pump was calibrated.

May 5, 3.30 p.m.—Wind steady from the east. Passed 10,000 cc. through the solution, taking the air through the automatic

apparatus at B. The direction of the wind was not favorable for bringing products of combustion of the works into the apparatus. The solution exposed in the air-selecting apparatus since May 1 contained 0.0047 g. of SO_3. The air examined on the spot contained 0.42 g. SO_2 per cu. meter.

May 16, 3.15 p.m.—Wind squally, about SW. Atmosphere damp and threatening rain, which descended in torrents in the evening.

Points A, B and C were established by survey and the contents of the fixing-flask were taken for analysis.

May 29.—Wind E. of S. and day cloudy. No visible smoke passed over the lawn but an odor was noticeable. At 4.25 p.m., the wind had shifted to W. Passed 10,000 cc. through solution VII.

During the succeeding fortnight plans were put together and a tracing made on vellum. The points occupied as stations of observation were platted on this map.

June 6.—Temperature 92°. The weather was very oppressive. Wind variable and gusty from SW. to W. Heavy rain fell as a test was about to be made.

June 9.—Temperature 80°. Wind variable, but generally SW. and W. No smoke visible over lawn. 10,000 cc. of air were passed through a half-saturated solution of sodium carbonate, and called VIII.

A second test was made by passing 10,000 cc. of air through a $\frac{2}{5}$ saturated solution, called IX.

June 15.—Wind SE., but shifted to SW. and W.

Two $\frac{1}{2}$ saturated solutions were prepared, through each of which, X. at station DA, and XI. at E, were passed 10,000 cc. of air.

While making the last collection the wind changed again and heavy volumes of smoke were poured over the site of the station first occupied.

June 17.—Wind SW., variable and puffy. Sky cloudy. 10,000 cc. of air were passed through solution XII. at station D, and an equal quantity through XIII., Station F.

June 20.—Wind variable from NE. and E. With Mr. John Frazer, occupied a point to the west, G. The smoke rose high but its odor was noticeable. 10,000 cc. of air were passed through solution XIV. Afterwards a similar volume of air was passed through solution XV. at E.

Collections and determinations XVI. to XXIV., inclusive, will be found in Table III., p, 393.

Sept. 12, 8.30 a.m.—Wind SW. to W., but variable. Passed 10,000 cc. of air through XXV. at DA.

In spite of the heavy rain which had fallen during the entire previous day and night, the branches and leaves were covered with black smut, which soiled any object touching it.

Specimens of the withered leaves of an American beech-tree were gathered for analysis 12.

An old and a younger hemlock hedge had lately been trimmed by the gardener and the sickly parts removed. Specimens of each and of a Norway spruce were taken for analyses 1, 2 and 3.

A visit was made to a country-place about ¼ of a mile to the north. Here was a hemlock hedge planted 32 years ago. The gardener stated that the vegetation shows no injury from smoke, and no unusual amount of smoke is noticeable, except from a small saw-mill in the neighborhood which burns soft coal with its shavings.

Sept. 16, Noon.—Wind W. to SW., variable. Took specimens of the subjects of analyses 1, 2, 3, 4, 7, 12, 13, 14. Occupied a new station at H to the west, where 10,000 cc. of air were passed through solution XXVII. No odor of smoke.

Sept. 26.—Eight porcelain crucible-covers were weighed, coated inside with vaseline, and re-weighed.

These were placed at various carefully noted points on the place, and left to collect the soot, care being taken in the selection of points to avoid other contamination.

Cloths saturated in litmus solution were also suspended at various locations.

Specimens of soil were taken from the villa grounds, from the place to the north previously mentioned, and from "Airdlie," and Silver Lake in Pike county, Pa., for analysis and comparison as to sulphuric oxide content.

Oct. 7.—Wind N-by-E. Temp., 42°. Clear.

The porcelain covers left eleven days ago were collected. Several of these were, from various causes, not able to furnish reliable tests, and were rejected.

A new and larger pump was arranged for future experiments.

Oct. 14.—Visited works near those suspected of contaminating the air, to ascertain how much of the smoke-injury could be ascribed to the former. The works visited consume about

8,000 tons of bituminous coal per year, and have five smoke-stacks, from which, at the period of the visit, little or no smoke could be seen to issue. Two Hawley down-draft furnaces were in use. Mechanical stokers had been used, but subsequently abandoned.

Oct. 21.—Subjects of analyses 1, 2, 3, 12 and 14 were collected, as well as a specimen of soil from near the hemlock hedges, for analysis. Observations of the smoke were made from a hill opposite the works.

Oct. 27.—At 9.21 a.m. a site was selected and located by compass and measurement from which to observe the smoke. This site is lettered "I" on the map.

Wind NE. to E., variable. Occupied station H and passed two measured volumes of air, each through a separate solution.

The first experiment failed owing to a defect in the new pump, tried for the first time. The second experiment, with the old pump, was successful. Passed 10,000 cc. through solution numbered XXIX. Odor of smoke occasionally noticeable.

Occupied station I and passed 10,000 cc. air through a solution marked XXX.

From 10 to 11 a.m. the wind varied from a trifle W. of N. to NE., and finally at noon it was nearly E., carrying much smoke over the lawn. At 4 p.m. the wind was very light. The columns of smoke and steam were nearly vertical. Black masses of smoke poured out of the ventilators of one of the buildings and also from the stacks behind this building and from the boiler-house to the SE.

II. Proof by Qualitative Determination of Sulphur Oxides in the Atmosphere.

The experiments with the saturated cloths, of which the results are condensed in Table I., furnished a striking and conclusive proof of the amounts of sulphur dioxide and trioxide (SO_2, SO_3) with which the air was charged at intervals. Pieces of cloth, 27.94 by 16.14 cm. in area, and weighing each 1.896 g., collected from the air in four days amounts of SO_3 varying from 6.8 to 10.85 per cent. of this weight. Similar cloths exposed for 22 days showed a smaller content of this gas; which was due to the fact that a portion of the fluids with which they had been saturated during the prevalence of damp weather, dripped from them to the under side of the containing barrel.

It was not established by these experiments at what period the maximum was reached, but only that the air contained at intervals quantities of sulphur oxides much more than enough to effect the observed destruction of plants.

Roman numerals are employed for the analyses establishing the existence of sulphur oxides in the atmosphere. Those from I. to VI., inclusive, are applied to the qualitative, and VII. to XXXI., inclusive, to the quantitative determinations. At A, analyses I. and II. were made; at B, analyses III. and IV. (IV., however, was lost); and at C, analyses V. and VI.

Analyses I., II., IV. and VI. were to determine the sulphur trioxide content of the fixing-bottle in the automatic air-selecter.

I. Collection from April 24 to May 1.
II. Collection from May 1 to May 5.
IV. Collection from May 5 to May 16.
VI. Collection from May 16 to May 29.

All of these showed qualitatively the presence of SO_3, which must have entered the apparatus from the direction of the industrial works.

Nos. III. and V. were experiments with measured quantities of air forced through the solution by the pump.

No. III. was rejected, owing to doubt of the correct adjustment of the apparatus. No. V. was lost during analysis.

TABLE I.—*Proof of the Existence of Sulphur Oxides in the Air, from Experiments with Saturated Cloths Free from Sulphur.*

Station Where Exposed.	Period of Exposure, 1905.	Distance and Direction from the Northwest Corner of the Westernmost Building of the Works.	Per Cent. of Weight of Cloth.		Remarks.
			Ash.	SO_3.	
A	March 28 to 31.	731 ft. W. 37° N.	1.44	10.85	
A	March 31 to Apr. 22.	731 ft. W. 37° N.	....	6.06	
B	March 28 to 31.	84 ft. W. 39° N.	1.53	10.54	Analysis "B, March 31 to April 22" was lost.
C	March 28 to 31.	675 ft. N. 44° W.	0.72	6.8	
C	March 31 to Apr. 22.	675 ft. N. 44° W.	....	7.16	

III. Analyses of Vegetation.

This investigation follows the lines of the most important researches made on the subject of smoke-injuries during the past 25 years in Europe and this country. The key to an interpretation of the results may be thus shortly stated:

1. After an immense amount of experimentation with plants growing in their native places, and with those transplanted to research laboratories, it is universally conceded by all competent investigators that the amount of damage to plant-growth from all other inorganic causes is a negligible quantity compared to that by the vapors of gases of HF, HCl, oxides of nitrogen, and especially oxides of sulphur.

2. Except in a few isolated cases, all of these but the last may be neglected.

3. Even in the vicinity of metallurgical works the amount of injurious gases evolved from the fuel is much greater than that produced by the metallurgical processes.

4. The ultimate source of the injury is to be sought in the oxidation and volatilization of the sulphur existing largely as pyrite and other sulphides in the coal. Wood-fuel is entirely free from this noxious ingredient.

5. The injurious action of the sulphur oxides which ultimately become acids, and which are thrown into the atmosphere by the combustion of pyritiferous coal, is intensified by the imperfect combustion of the coal, and the consequent production of soot, a greasy hydrocarbon which becomes saturated with the acid and keeps the spots on which it is deposited constantly moistened by this most deadly of poisons to vegetation.

6. A percentage of over 0.30 SO_3 in the ashes of the needles of evergreens, or leaves of deciduous trees, has been found, in the German forests, to indicate an unhealthy condition, except where there is an unusually large amount of sulphur compounds in the soil. It is not safe to assume this limit as applicable to other and especially to distant regions, but it may be safely held that 0.5 per cent. of sulphur trioxide in the needles, leaves, or twigs of plants is an indication that the plant is being poisoned by the absorption of the products of combustion in the air, through its organs above the ground.

7. Owing to the extreme solubility of all the ordinary sulphur oxides in water, and the free circulation of water in the

ground, the poisoning of vegetation by sulphuric acid through its roots, in any case not artificially arranged for the purpose, may be dismissed as highly improbable.

8. Where the external parts of plants are constantly exposed to this poison through years, the percentage in the leaves shows a slightly accelerated increase with their age. Younger plants with more vitality, on the whole, show fewer symptoms of disease and approaching death than older plants, because they are better able to survive the successive impairments of the leaf-organs, and also to eliminate the active cause of destruction.

9. For the purpose of ascertaining how far a local source of contamination of the atmosphere is responsible for the injury to the vegetation in an adjoining district, it is necessary to determine: (*a*) that the injury is unquestionable; (*b*) that the percentage of SO_3 in the external organs of the plants is above normal; (*c*) that this is not due to the absorption of sulphates from the soil by the roots (some of which, like calcium sulphate, are nutritious and of direct benefit); (*d*) that vegetation of the same kind on practically the same soil, but more distant from the suspected source of contamination, contains a smaller percentage of SO_3.

In Table II. (page 390) these items are given.

Altogether fourteen specimens of vegetation were chosen for analysis, as follows: 1. Young hemlock hedge near green-house, 10 years old. (Position marked on the map.) 2. Hemlock hedge 14 ft. high, 50 years old, near green-house. (Position marked on the map.) 3. Norway spruce nearest to furnace and unprotected. (Position marked on the map.) 4. Hemlock from road running through woods west of house in direction of Cummins' Run, Airdlie, near Milford, Pa.; Apr. 15, 1905. 5. White-pine needles from young tree 50 ft. N. of house, Airdlie, Westfall township, Pike county, Pa.; Apr. 15, 1905. 6. Young white-pine from corner of woods at entrance of wood-road west of house, from Airdlie, near Milford, Pike county, Pa.; Apr. 15, 1905. 7. Young hemlock ($\pm$ 4 years) from Sap Swamp Meadow, $\pm$ ¼ mile N. Edgemere Club House, Pike county, Pa.; Apr. 16, 1905. 8. Spruce trees from near Edgemere Club House, Pike county, Pa.; Apr. 16, 1905. 9. Spruce from Sap Swamp Meadow, ¼ mile NE. of Edgemere Club House; Apr. 16, 1905. 10. White-pine from Sap Swamp

TABLE II.—*Analysis of Vegetation.*

No.	Date of Collection, 1905.		SO_3 in Needles or Leaves.	Ash in Needles or Leaves.	SO_3 in Ash.	SO_3 in Soil.
1.	March 31.	*a*	0.813*d*	3.42	23.77	......
	Sept. 16.	*b*	1.05	4.39	23.92	......
	Oct. 21.	*c*	0.88	....	....	......
2.	March 31.	*a*	1.03	3.596	28.64	......
	Sept. 16.	*b*	1.01	4.95	24.94	0.1
	Oct. 21.	*c*	0.86	....	....	......
3.	March 31.	*a*	1.08	7.11	15.19	......
	Sept. 16.	*b*	1.06	6.24	16.98	......
	Oct. 21.	*c*	0.99	....	....	0.34
12.	Sept. 12.	*b*	2.35	9.78	24.01	......
	Oct. 21.	*c*	1.61	....	....	......
14.	Sept. 12.	*b*	1.66	8.23	20.17	......
	Oct. 21.	*c*	1.98	....	....	......
4.	April 15.	*a*	0.296	3.05	9.7	......
	April 15.	*b*	0.47	3.89	12.08	0.08
7.	April 16.	*b*	0.42	3.35	12.53	0.07
13.	Sept. 12.	*a*	0.60	3.64 *e*	16.48	0.05
	Sept. 12.	*b*	0.84	4.27	19.69	0.5

a Analysis by John Frazer.
b Analysis by J. K. H.
c Analysis by C. F. M.
d Mean of two determinations.
e Mean of three determinations.

No. 1, Needles of hemlock 10 years old; 2, Needles of hemlock 50 years old; 3, Needles of Norway spruce; 12, American beech, much exposed; 14, American beech, less exposed; 4, Needles of hemlock from Airdlie, Pike county, Pa., free from any contamination by the air; 7, Needles of hemlock 4 years old, from Pike county, Pa.; 13, Needles of hemlock from country-seat, $\frac{4}{5}$ mile to the north of the industrial works under consideration.

Meadow, ± $\frac{1}{4}$ mile N. of Edgemere Club House; Apr. 16, 1905. 11. Pitch-pine from Sap Swamp Meadow, ± $\frac{1}{4}$ mile N. of Edgemere Club House; Apr. 16, 1905. 12. American beech from very near the NE. line of the industrial works before mentioned. (Position marked on the map.) 13. Hemlock from country-seat $\frac{4}{5}$ mile N. of these works. 14. American beech on the lawn of the villa, but more remote than 12 from the works. (Position marked on the map.)

The numbers were given to the objects in the order of their analysis; but in the preparation of the table the analyses of the vegetation of the villa were put together. For this reason analyses Nos. 12 and 14 follow No. 3. Eight analyses were

made of vegetation in Pike county, nearly a hundred miles distant: to wit, three from Westfall township, near Milford, and five from Delaware township on the high hills back from the river of that name. It was useless to record on the table all of these analyses of very remote plants, and therefore only two analyses (Nos. 4 and 7), one from each township, were selected as typical.

Nos. 1, 2, 3 and 12 are hemlocks and deciduous trees of the villa, exposed by the currents of air to the vapors and gases from the works, which are close to them. No. 14 is also from the villa, farther from the works and more sheltered than the rest by position. No. 13 is a hemlock similar to Nos. 1 and 3, and growing on similar soil, but nearly a mile distant, and therefore presumably less likely to suffer from the furnace-gases. Nos. 4 and 7 are plants selected from a distant part of Pennsylvania (Pike county), where contamination through the air is unsupposable.

From an examination of the data it will appear that all the analyzed plants from the villa showed much greater total quantities of SO_3 in the needles or leaves, and in the ash, than the hemlock No. 13, which was distant from the works. The quantity of SO_3 in the soil was also greater in Nos. 1, 2, 3, 12 and 14 than in No. 13, but it was so small in both cases that it could not have exercised any important influence on the results of the analyses.

The plants from Pike county (Nos. 4 and 7) are too remote to be of any value for comparison if there were any notable difference of sulphur compounds in the soil in the two localities; but as this is not the case, they offer a striking illustration of the difference of SO_3 content between the vegetation in an industrial city and that of a virgin forest, even when the natural supply of sulphates from the soil is nearly the same in both cases.

IV. Quantitative Determination of Sulphur in the Air.

The object of this examination was to fix the amounts of the plant-poison in the air during the prevalence of winds from various quarters, and to compare these amounts with others present when the wind was blowing directly from the works adjoining the villa.

If it were found that the sulphur oxide percentage in the air invariably decreased with the divergence of the wind from the quarter occupied by these works, the conclusion would be justified that the works were supplying the harmful agent.

But this question is always the most difficult to determine, and especially in large industrial neighborhoods. Thousands of industrial and domestic chimneys are pouring out furnace-gases, and it might be plausibly argued that it is not just to single out one of the very many sources of these gases to bear the entire blame of pollution.

In this particular instance, other establishments lie around the southern skirt of the nearest works. In addition to this, several main and auxiliary lines of railway add to the contamination of the air. It would seem at first sight very difficult to fix the responsibility where so many offenders are concerned.

During the observations here tabulated, the locomotives on the various railroads above mentioned did not vitiate the results by adding any appreciable quantity of sulphur oxides to the air taken for examination.

The plan of the experiments was to get successive couples of observations during the continuance of a wind, the one to windward, and the other to leeward, of the works under investigation. But as it was found impracticable to occupy stations to the south or east of the works, stations on the north and west sides were occupied, and these stations sufficed, because the house and conservatories are situated in the northeast corner of the property and an east wind could only bring its noxious burden to the outlying parts of the property to the southwest.

DA, D, E and F were four stations just north of the extreme NE.–SW. boundary; stations B and I were immediately north of them; and stations G and H on the west side of the works.

With a southeasterly wind, therefore, stations D and DA would receive a portion of the products of combustion of all the fires in the city to the southeast, and, in addition, those evolved by the works. At stations G and H, on the contrary, with this same wind, all the former would be obtained but none of the latter.

The collection of these sulphur oxide gases was effected by pumping a measured quantity of the air into a flask containing

TABLE III.—*Determinations of SO_3 in Measured Portions of Air Examined.*

	Number.	Station	Date, 1905.	Grams SO_3	Grams p. cu. M	Remarks.
	VII.	B	May 29.	Analysis	rejec'd	Wind W. Very little smoke, but odor perceptible. 10,000 cc. air.
l	VIII.	B	June 9.	0.0017	0.17	Wind variable, generally SW. to W. No visible smoke over lawn. Half saturated solution. Fine aperture delivery tube. 10,000 cc. air passed.
l	IX.	B	June 9.	0.0003	0.03	Wind as in preceding. ⅔ saturation. 10,000 cc. passed.
m	X.	DA	June 15.	0.0004	0.04	Wind variable, very light. Shifted from SE. to SW. before commencement. 10,000 cc. air passed.
m	XI.	E	June 15.	0.0003	0.03	Wind shifting. Smoke poured over station after experiment was made. 10,000 cc. air passed.
n	XII.	D	June 17.	0.0029	0.29	Wind SW., variable and puffy. Cloudy sky.
n	XIII.	F	June 17.	0.001	0.10	Wind SW., variable and puffy. Cloudy sky.
o	XIV.	G	June 20.	0.0005	0.05	Wind easterly, variable. Smoke rose high.
o	XV.	F	June 20.	Analysis	lost.	Wind easterly, variable. Smoke rose high.
p	XVI.	D	June 26.	0.0002	0.013	Wind SW., steady. Odor of smoke perceptible. 20,000 cc. air passed. Mean of two determinations.
p	XVII.	D	June 26.	0.0	0.0	Wind W–SW. No smoke visible.
q	XVIII.	B	June 27.	0.0	0.0	Wind N. shifting to NW. Clear. Fairly steady.
q	XIX.	D	June 27.	0.0	0.0	Wind N. Clear. No odor.
r	XX.	D	June 30.	0.0032	0.16	Wind S. to SW., rather steady. Clear. Smoke visible on place. 20,000 cc. air passed through solution.
r	XXI.	G	June 30.	0.0	0.0	Wind S. to SW., rather steady. Shifted slightly to S. Passed 10,000 cc.
	XXII.	D	July 1.	Analysis	rejec'd	Wind S., steady. Cloudy. Considerable smoke and odor. 20,000 cc. air passed.
s	XXIII.	D	July 1.	0.0001	0.01	Wind S. to SW., cloudy. Odor of smoke noticeable. 10,000 cc. air passed.
s	XXIV.	B	July 1.	0.0	0.0	Wind W. of S. Cloudy. Wind light. 10,000 cc. air passed.
	XXV.	D	Sept. 12.	0.0	0.0	Wind SW. to W., variable. No smoke visible blowing on lawn.
t	XXVI.	D	Sept. 16.	0.0005	0.05	Wind SW. to W. At times smoke visible over station. Odor noticed.
t	XXVII.	H	Sept. 16.	0.0005	0.05	Wind SW. to W. At times smoke visible over station. Odor noticed.
	XXVIII.	H	Oct. 27.	Analysis	rejec'd	Wind NE. to E., variable. New pump tried for the first time: not in order. Result canceled.
u	XXIX.	H	Oct. 27.	0.0019	0.19	Wind NE. to E., variable. Old pump.
u	XXX.	I	Oct. 27.	0.0016	0.16	Wind NE. to E., variable. Old pump.
	XXXI.	J	Nov. 32.	0.0005	0.05	Wind S. 40° W.

sodium carbonate solution. Generally 10,000, but in some cases 20,000 and up to 45,000 cc. of air were taken.

The following records are given in grams of sulphur trioxide contained in 100 cu. m. of air, this volume having proved the most convenient to avoid fractions without unduly increasing the record numbers. No amount smaller than 1 g. of SO_3 per 100 cu. m. was noted in any of the experiments.[1]

The winds were usually variable, and during the half hour or more necessary for a single experiment they frequently shifted, so that two determinations at the same point and immediately succeeding each other were not entirely alike. This variability is sometimes indicated by converging arrows platted from the two directions between which the variability was noticed; in other cases, where less accuracy was required, a waved line for the shaft of the arrow expresses it. The stated directions of the wind give the earlier direction first and the point to which the wind shifted last. It frequently happened that the direction of the air during the experiment passed from a quarter partly affected by the furnace-products of the works to a quarter entirely unaffected by them, as in the first experiment, shortly to be explained.

Analysis VII. was rejected.

For the purpose of facilitating a comparison of the results, and to avoid using letters which had been used for stations on the map, a letter was employed for both of the paired determinations, beginning with the letter "*l*."

Thus "*l*" was used for determinations VIII. and IX., made June 9 at station B, with the wind shifting from SW. to W. During the first experiment, while its direction more nearly coincided with that of a line to the works, the air proved to contain 17 g., while in the second case, where it had changed so as to clear the works entirely, only sulphur oxides sufficient to produce in the analysis 3 g. per 100 cu. m. of SO_3 were found. This pair of observations is marked "*l*" on the map.

The pair of observations "*m*" were taken, respectively, X. at B and XI. at E, on June 15. The wind shifted from SE. to

[1] Much if not the greater part of the sulphur oxides was carried by the air as SO_2, but was combined in its sodium salt as SO_3. In the statements of grams per 100 cu. m. is meant that the sulphur oxides of all kinds left by the air in its passage through the fixing-flask when converted to sodium sulphate represented so many g. SO_3 per 100 cu. m. of that air.

SW. The selected unit volume showed 1 g. more sulphuric oxide when the direction was most nearly from the works.

A much clearer proof of the responsibility of the works is found in the paired observations "*n*" (XIII. at D and XII. at F). With a variable SW. wind, part of the combustion-products of the western works would be carried to D, but not to F with the same wind. The difference is very marked; there being at F one-third of the amount of SO_3 which was detected at D.

Experiment XVI. was made on June 20, and was isolated on account of an accident which happened to the analysis of its companion, No. XV. It shows that with an easterly wind passing very high over the works, 5 g. of SO_3 per unit volume were present.

Couple "*p*" consists of observations XVI. and XVII., taken on June 26, at station D; the wind in the first being SW. and carrying 1 g. SO_3 from the contaminating quarter, while the second, with a more westerly wind, showed no sulphur-compound.

Couple "*q*" (XVIII. at B and XIX. at D) gives important information, clearing the part of the city north of the villa from inculpation in the injury to vegetation. With a north wind both records are 0.

Couple "*r*" (XX. at D and XXI. at "G") is very instructive. With a SW. wind the air showed 16 g. SO_3 per unit volume, whereas with the same wind at G, west of the works, the content of SO_3 was 0.

Analysis XXII. was rejected.

Couple "*s*" (XXIII. at D and XXIV. at B) is equally significant. With a SSW. wind, at D the air showed 1 g. SO_3 per unit volume, whereas at B with the same wind it showed no sulphur-content.

XXV. is an isolated analysis at D. Wind not from works. No sulphur oxides.

Couple "*t*" (XXVI. at D and XXVII. at H) showed each 5 g. per unit volume, with the wind varying from SW. to W.

Analysis XXVIII. was rejected.

Couple "*u*" (XXIX. at H and XXX. at I), with the wind NE. to E., variable, showed 19 g. and 16 g., respectively. As would have been expected, there was a larger percentage of sulphur oxides in the air at the former than at the latter sta-

tion, because these winds would carry more of the furnace-gases to H than to I.

From all these observations it follows that the acid gases in the atmosphere which have killed and are still killing the plants at the villa, come in largely preponderating amount from the adjoining works.

The injury to the vegetation of the villa by possible furnace-gases emanating from any direction of the compass except from the quadrant between east and south (in which the works lie) may be practically neglected.

The lines indicating the direction of the wind observed at each station, with the number of the observation, and the percentage of SO_2 determined, will be seen upon the chart. The accompanying letters and figures will be easily understood.

Thus, "B. 6.9 VIII. 17" means that at station B (where the note will be found, the direction of the wind being indicated by the arrow), on June 9, experiment VIII., the air contained 17 g. of SO_2 per 100 cu. meters.

Where fewer figures and letters are used, the Roman numeral stands for the number of the experiment, the letter for the station, and Arabic numerals for the number of grams of SO_2 which the air contained per 100 cu. meters.

V. Examination of Soot Emitted by the Works.

The proof of the existence of soot in the atmosphere and of the principal source from which it is supplied is extremely easy. On any day when the wind is from the direction of the nearest works large volumes of unconsumed hydrocarbons may be seen pouring out of certain stacks, may be traced through the air in their course, and occasionally may be seen and felt in the act of depositing themselves on the person of the observer.

Cloths were suspended in different parts of the property and were soon covered by the mixture of unconsumed carbon and hydrocarbons from the combustion chimneys, with metallic oxides (usually ferric oxides) from the process stacks. If the cloth were white it changed in a day or so to gray, and in spots to black. Every plant and permanent fixture of the villa exposed to the wind from the works is covered with this deposit.

On Sept. 26, pieces of white paper were pressed against the stalks of the grass in the fields and drawn rapidly upwards.

There was left a deep black mark, as was the case when one of the stone balusters or the rail of the steps was wiped with a piece of white paper.

Even the objects inside the house were not protected by the closed doors and windows. The doors and windows of the drawing-room, during the absence of the occupants in July and August, were constantly closed; yet white curtains which had remained suspended there during this time were blackened and soiled.

That the soot came almost exclusively from the nearest works and was largely due to improper firing is proved by the fact that on one occasion when the smoke was unusually annoying, during a visit of one of the then officers of the works to the villa, he gave such directions that on the following day and for some time thereafter the nuisance was very much abated.

In order to ascertain as nearly as possible how much soot was being carried over the place and how it was being deposited, Mr. John Frazer prepared eight porcelain crucible-covers, placed on the inner surface of each a layer of vaseline, and afterwards weighed them with the additional substance.

These were numbered consecutively, and placed as follows: No. 1, on the west corner of the main porch under the roof; No. 2, on the east side of the main porch; Nos. 3 and 4, on the leeward side of the house, No. 4 nearest the kitchen; No. 5, on the south side of the portico roof of the small house (see map); No. 6, on the north side of the small house under the eaves; No. 7, on the south side of the cart-shed; No. 8, on the north side of the cart-shed.

The area of each of these porcelain crucible-covers was very closely 14 sq. cm. (2.17 sq. in.).

They were collected on Oct. 7, eleven days after they had been put in place.

The covers, first weighed, to ascertain by difference the amount of added soot and dust, were then incinerated and weighed a third time to determine, by subtraction of the weight of the original crucible-covers, the amount of the incombustible matter or dust; this weight added to the weight of the vaseline and subtracted from the second weighing, gave the amount of the soot.

The results are shown in Table IV.

TABLE IV.—*Amounts of Soot and Dust Deposited in Eleven Days.*

	Combustible Matter. (Soot.)		Incombustible Matter. (Dust and Ash, principally Fe_2O_3.)	
	Deposited on 14 Sq. cm.	On 1 Sq. meter.	On 14 Sq. cm.	On 1 Sq. meter.
	Grams.	Grams.	Grams.	Grams.
No. 1..........	0.0012	0.857	0.0010	0.714
No. 2..........	0.0008	0.571	0.0012	0.857
No. 3..........	Lost.			
No. 4..........	Lost.			
No. 5..........				
No. 6..........	0.0004	....	0.0005	
No. 7..........				
No. 8..........				

This means that in the course of eleven days from 0.5 g. to 0.8 g. of soot were deposited on every square meter over the villa.

It is not safe to ascribe all the incombustible matter to the establishment examined, but certainly the larger part of it, which consists of ferric oxide, may be thus ascribed; for this compound is one not frequently met in the impurities of ordinary air, but is quite common in the neighborhood of works engaged in the manufacture of iron and steel.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Bibliography of Injuries to Vegetation by Furnace-Gases.

Summaries and Synopses of Treatises Arranged in Chronological Order, to Accompany the Author's Paper, "A Search for the Causes of Injury to Vegetation," etc., read by title at the London Meeting, July, 1906.

BY PERSIFOR FRAZER, PHILADELPHIA, PA.

CONTENTS.

1. Smoke Prevention. Report of Select Committee of House of Commons (1843).

Nuisance considerably abated in Leeds (Wm. Backerd, July 13, 1843, 239 pages).

A synoptic index, p. 211, gives, in alphabetical order, the digest of every subject taken up.

2. Fuel: Its Combustion and Economy. D. Kinnear Clark, C.E. 24mo, 354 pp. Crosby Lockwood & Co., London (1880).

Includes abridgement of treatise on combustion of coal and prevention of smoke, by C. W. Williams, A.I.C.E.

3. Die Rauchschäden in den Wäldern der Umgebung der fiscalischen Hüttenwerke bei Freiberg. Dr. J. v. Schröder, Professor in Tharand, und Dr. A. Schertel, Vorstand des Hüttenlaboratoriums zu Freiberg. Royal 8vo, 27 pages, 19 pages of tables and a map. Ernst Maukisch, Freiberg (1884). (Aus dem *Jahrbuch für das Berg- und Hüttenwesen*, 1884.)

In 1861, Reich and Stöckhardt examined the extent of injury to vegetation by the Muldner works.

Needles and twigs of pine showed in 100,000 parts: Pb, 5 to 50; As, 3.3 to 14.3; SO_2, 62 to 120. In the top twigs, 5 to 8; needles, 10 to 16; thicker twigs, 10 to 22; thinner twig-ends, 17 to 54 of lead. Lead greater in amount in sickly twig-ends with few needles; also in the bark than in the naked wood of the trunk, which had hardly a trace; also in the part turned toward the works than on the opposite side. Pb and As diminished in the vegetation with distance from the smelter; and the same with regard to the soil. Fresh snow was collected, and SO_2, As, and Pb detected in it.

The authors showed that after repeated smoking with soot and arsenic-vapors, and sprinkling with white-lead, the growth of the plants was not injured. Their conclusion was that to the SO_2 in the smoke and the metallic poisons in the soil must be ascribed the injury to vegetation. The chronic poisoning by SO_2 is through Stöckhardt's experiment on pine-trees indubitably proven. Nobbe experimented on vegetation in earth treated with solutions of As and Pb and mixed with these salts. These investigations, as well as the results of other experiments, are given in the work of Schröder and Reuss.

Reuss has shown that the general injury as well as its intensity can be measured by the entire content of H_2SO_4 in the organ of the leaf; or rather the surplus of H_2SO_4 in the injured over that in the uninjured organs of the same plants in the same region.

The normal percentage of healthy pines from regions adjoining the smoke-affected area was 0.162 per cent. That in the area in which injury is just observable to the eye was 0.210 to 0.300 per cent.; in the second (higher) grade of injury, 0.3 per cent. to 0.5 per cent.; in the third, 0.5 and upwards.

The increase of H_2SO_4 is not due to the sulphates deposited on the needles by the floating dust. The content of H_2SO_4 in the ash of healthy regions was 5.47 per

cent.; in those of the first grade of injury, 7.67 per cent.; in the second, 10.65 per cent.; in the third, 17.09 per cent.

The H_2SO_4 determination was made in the following way: The needles freed from all the twigs, having been dried and well powdered, were stirred to a thin decoction in a solution of sodium carbonate and distilled water in a platinum dish, and evaporated to dryness. The residue was charred (*verkohlt*) and treated with water. The leached coke was then completely incinerated. The ash was then united with the extract, the solution evaporated, and treated with an excess of HCl and precipitated (after precipitation of the silica) by $BaCl_2$.

For determination of the metal-content 100 g. of the dried needles were treated with dilute HCl, the solution treated with $KClO_3$ in moderate heat, to decompose the organic substances, filtered, and precipitated by H_2S. The precipitate was then used to determine in the usual way As, Pb, and Cu. The undissolved residue from the extraction of the needles was carefully reduced to ash in the muffle-furnace, treated first with Na_2CO_3, and, after thorough washing, with dilute HNO_3, the solution precipitated by H_2S, whereby a further portion of Pb was precipitated, and the filtrate added to the filtrate of the first sulphhydrogen precipitate, to determine the zinc oxide.

The maximum percentages of H_2SO_4 found by Schröder and Schertel in the needles of pine-trees unquestionably healthy, not too near the smelters, and which certainly had not previously been subjected to smoke, were as follows: 0.204, 0.213, 0.223, 0.234, 0.226, 0.234 per cent. H_2SO_4.

No signs of injury are visible in vegetation showing less than 0.250 per cent. H_2SO_4. If one plat on a map the area within which a percentage of 0.230 H_2SO_4 is found, it is no longer a closed region, and one would see in the continuous forest-areas of Zellaer, Tharand, Struth and Freiwald small island-like patches of injured vegetation surrounded by healthy trees.

All the forest-areas in which the needles contain 0.250 per cent. and upwards of H_2SO_4 can be inclosed by the periphery of an elliptical area of which the main axis runs northwest and southeast. South of the Mulda works, and on the left bank of that stream, the greatest damage has been done—maximum, 0.292 per cent. (much less than that of the Harz, which is 1.33 per cent.). On the road from Weissenborg to Lichtenberg, opposite the wood-manufactory in Berthelsdorf, the pines are sickly, with black misshapen needles, and 0.238 per cent. H_2SO_4. It lies exposed to the high chimney of the Mulda, but the manufactory chimney is the immediate and preponderating cause of the trouble. A test of trees in Butze's woods, though apparently uninjured, showed 0.442 per cent.

Near Gesegnetes Bergmann's Glück all the trees seem to be affected, but the percentage of H_2SO_4 is only 0.285. A test opposite the Münzener Hammer and the wood-planing mill shows 0.488, which is explained by a union of the effects of the Münzner, the Halsbrücke, and the locomotive smoke. It was not possible to draw concentric lines with the smelters in the center showing the more and the less injured areas, as has been done for the Oberharz, because the Muldner works are not inclosed by woods, and the chimney-gases are not so acid.

The percentage of metal oxides is not parallel with that of H_2SO_4. As, Sb, and Pb do not seem to poison the vegetation, as they are found in the healthiest patches. These metal oxides are deposited as dust on the needles and are therefore much affected by the condition of the weather—dry or wet, etc.

The metal oxides are not exclusively due to the furnace-gases, but may be derived from the sulphides, galenite and zinc-blende in the gneiss. Zn, Cu, As, etc., find their way to the vegetation through the weathering of the rocks.

The conclusions reached by the authors are:

1. The areas affected by the furnace-gases are certainly defined. Beyond these limits the injurious action will not extend in the future because constantly increasing provisions for condensing the noxious constituents are being made.

2. In the district affected by the Muldner works the injury not only has been diminishing since 1865, but also since the taxation by the Committee in 1876.

3. Münzner's machine manufactory and wood-planing works in Obergruna has its part in the injury by furnace-gases which appears in the Mulda valley below Hohentanne and to the confluence of the Mulda and Bobritzsch.

Though it is very difficult to express in figures the relative responsibility of the different sources of contamination, it is unfair to consider only the action of the smelter furnace-gases.

4. Smoke-Nuisance Abatement (Metropolis) Bill. Report of Select Committee of the House of Lords, with the Proceedings of the Committee and Minutes of Evidence. 321 pp. Eyre & Spottiswoode, London; Adam & Charles Black, Edinburgh, and Hodges, Figgis & Co., Dublin.

Mr. Wm. R. E. Coles, Engineer appointed by the Home Secretary to examine furnaces, in the metropolis, complained of for causing smoke nuisances: I report to the Commissioner of Police. . . . Also am Honorable Secretary to "Smoke Abatement Institute."

Prevention or mitigation could be attained from the nuisance due to private houses by alteration of the structure of the grates, and by change of the fuel.

By the first, the new coal is put under the fire instead of on top. Better still is the method of altering the draft so that the burning takes place at the top and the combustion-products are carried down to the flues which connect them with the chimney.

The second method is that of using anthracite coal instead of bituminous. There is a vast quantity of anthracite coal in Wales. This or coke or gas could be employed. Mr. Davis, an Inspector, found when he used coal for heating and cooking and gas for lighting he consumed 51,000 cu. ft. of gas and 22 tons of coal per year. Another year, using gas for cooking and lighting and gas-coke for heating the rooms, he required 53,500 cu. ft. of gas for lighting, and 34,500 for cooking. The first year the coal and gas bills amounted to £24 11s. 6d., and in the second £16 18s. 3d. The only alteration necessary in burning coke instead of coal was to have fire-brick backs and jambs instead of iron.

Mr. James Edward Davis: Legal adviser appeals by Home Secretary to the commissions. Evidence chiefly on application of Acts of Parliament to London.

Supdt. Cutbush: Evidence chiefly concerning administrative and legal aspects of the question.

Ernest Hart, Chairman of Council of National Smoke Abatement Institute: Description of "saucer-feed on under grate-bar," Sir Wm. Siemens's coke and gas together. Sir Wm. Siemens has said the ideal of smokelessness is gas fuel. Earl of Harrowly asks: "Were you in London at the time Lord Palmerston made his great movement against smoke?" . . . In the last 20 years smoke has made a perceptible difference in the health of the inhabitants. Roses could be grown at Princes' Gate, but that is now impossible. Roses could grow in Kensington Gardens; now the very last conifer is dying or dead there. . . . Seven of the best physicians agree as to the enormous increase of mortality owing to the smoky fogs. . . . A short time since the Thomson furnace was brought to the notice of the Council, and the engineer, Mr. D. K. Clark, C.E., was instructed to make a series of scientific tests of the apparatus. The tug "Alexandra" was fitted with the furnaces and ran from Temple pier to Richmond, lay there two hours and returned to Westminster without products of combustion being visible at the top of the chimneys except for about a minute each time the furnace was stoked, when a little pale

smoke was emitted. When the fires had got low they were stoked with coal-dust, which produced smoke for two minutes, but not of dark shade. The owners report a saving of 20 to 25 per cent. in fuel burnt. The sister tug to the "Alexandra" was passed several times burning identical coal in an ordinary furnace and emitting volumes of black smoke. . . .

It costs £28,000 per year to clean the surface of the House of Parliament, and Westminster Abbey is falling to pieces in the same way. . . .

Coke is cheaper than coal. . . . One can roast by gas.

In the time of fogs (black, artificial fogs), the rate of mortality rose to the rate in the great cholera year; the annual mortality to 40 in a thousand.

The London fog goes like a great wall down to the Surrey Hills.

5. Zinc and Lead Content of Burnt Blast-Furnace Gases. Albert Vita, *Zeitschrift für angewandte Chemie*, p. 69 (1890).

Since 1887, the gas-cleaning apparatus has been much improved. No amount of cleaning will suffice to prevent material losses of zinc and lead.

The furnace-gases were drawn by aspirator through five Bunsen wash-bottles filled in the order given with water, HCl, HNO_3, HBr, and alcohol, respectively, the last for the absorption of Br vapor. At each test not less than 82 liters were thus passed through. For one ton of iron produced an average of 13,296 cu. m. of burnt gases was developed; 3.89 kg. for 1 ton iron, etc.

6. Condensation of Carbon Particles in Smoke. Robert Irvine, F.C.S., *Journal of the Society of Chemical Industry*, vol. ix., p. 1110 (1890).

The author erected a glass structure provided with two iron plates, each with points. All parts of the surface but the points were covered with shellac varnish. On admitting a mass of smoke (from pitch-oil), so thick that a bright light placed at the opposite side of the chamber was completely obscured, he passed a current between the plates by a small dynamo. The effect was instantaneous, and the chamber was cleared of smoke almost entirely. If a smoked glass be examined under the microscope each particle will be seen to consist of amorphous carbon surrounded by an areola of oily matter. Rain does not precipitate it, on account of its water-proof covering, but air-currents which drive the particles together clear the fog off suddenly.

(Illustration of a smoked microscopic slide showing soot-particles with "areola" of hydrocarbons surrounding them.)

If commercial lamp-black or soot from imperfectly burned coal be treated, empyreumatic matter is driven off as a brown greasy substance consisting of crysene, pyrene, capnomor, etc., which cause lamp-black to cohere like a damp snow-ball when pressed.

In a newly made or mended fire only light blue and yellow-brown colored vapors are given off, consisting of solid or liquid hydrocarbons, which pass into the atmosphere. As the coal becomes heated, these burn with a smoky flame. At this stage, owing to the imperfect combustion of these gases, finely divided particles of carbon are formed and black smoke is added to the greasy volatile matter, making black or brown fog. Although the soot is only 3 per cent. of the mass, it powerfully obstructs the light. When the black fog disappears, without being blown bodily away, it is by the agglomeration of the minute soot-particles.

Rollo Russell estimates the coal consumed in London at 20,000 tons per diem, which at 2 per cent. makes 600 tons of smuts.

Mr. Elliott's washer draws the smoke from the stack by a fan and agitates it in a closed space.

There is no difficulty now in preventing smoke from any factory chimney.

Macaulay, in a lecture at Liverpool, February, 1888, estimates the annual waste of coal in England at 45,000,000 tons, valued at £15,750,000 at the pit-mouth.

7. Contamination of Air by Commoner Illuminants. E. Cramer, *Journal für Gasbeleuchtung*, vol. xxxiv., p. 27 (1891).

Comparison of values of tallow and paraffine candles, gas, etc., for standards in photometric experiments and heat-units, etc.

8. The Analysis of the Air of Large Cities. Editorial note on the Committee (Drs. Bailey, Cohen, and Tatham and Mr. P. J. Hartog), appointed by the Town Gardening Section of the Manchester Field Naturalists' Society. *Industries*, vol. x., p. 91 (1891).

The Section planned simultaneous analyses from seven different stations in Manchester and Salford to ascertain :

1. The comparative purity of air in densely and in sparsely populated districts.
2. The relation between atmospheric impurities and prevalent sickness and death.
3. The amount and distribution of noxious ingredients specially injurious to plant life—*e. g.*, SO_2.
4. The extent to which smoke and noxious gases are due (*a*) to dwellings, (*b*) to factories.
5. The nature of fog, and chemical character of air during the prevalence of fogs.

Dr. Bailey reported experiments had commenced. Snow carried to ground large quantities of HCl and H_2SO_4, also some elements of sewage. Depositions on leaves were in amount proportionate to population. The greatest injury to plants was due to emanations from dwelling-houses. He estimated that two tons of "blacks" and H_2SO_4 were deposited per sq. mile of city area.

9. The Noxious Vapors of Manure-Works. John Morrison, *Journal of the Society of Chemical Industry*, vol. x., p. 338 (1891).

Before the Alkali Act of 1881, the conditions connected with the manufacture of superphosphates from manure were frightful. Now it is much better. The noxious vapors must be distinguished from the powerfully offensive and searching stinks from bone-boiling and blood, fish, and flesh-offal treatment. Stifling fumes of mineral phosphates treated with H_2SO_4 consist of fluoric, carbonic, and sulphuric acids, and steam, and unpleasant oily vapors. On the Tyne four or five tons of HCl acid would be discharged from South Carolina River phosphate in a week. I have devised most of the apparatus for arresting manure-works vapors. These vapors contain all the ingredients necessary to deposit themselves, and but one condition—heat—to retard this. For this reason, opposed to use of steam, I cool by flues with baffling diaphragms. This takes out the solids. The gases traverse one or more water-towers, wet-scrubbers packed with wedge-shaped wood-spars, before emerging at the chimney. The draft is a forced draft by exhaust-fan.

In the discussion, Mr. Morrison said he preferred a flue of about 200 ft. between the mixers and scrubbers.

10. Inspection of Chemical-Works. Mr. Brunner, M.P., *Journal of the Society of Chemical Industry*, vol. x., p. 637 (1891).

In the discussion in the House of Commons on the local Government Board vote, Mr. Brunner said the law was in an anomalous condition. A number of alkali-works are prevented from discharging noxious vapors, but many smaller works using the products made at the larger are not prevented. If the Inspector can induce the smaller works to consume these noxious gases then they come under the Act.

11. The Manufacture of Iron in Its Relation with Agriculture. Sir I. L. Bell, *Journal of the Iron and Steel Institute*, vol. xlii., No. 2, p. 11 (1892).

The nutrition of plants is chiefly from the atmosphere. More carbon is stored there than in the crust in all forms. The ash of plants is 2.5 per cent. of weight,

and of this 2.5 per cent. is iron oxide. Annually a human body extracts only enough iron to make a wedding ring. One three-hundredth by volume H_2S introduced into the blood would interfere with the iron changes and the whole would be vitiated in 25 seconds, If all the H_3N gas in the atmosphere were collected at sea level and at the atmospheric pressure it would not be thicker than ¼-in. When fossil coal is thrown upon the fire all the hydrogen it contains unites with oxygen in forming water. Each ton of coal burnt gives 90,000 cu. ft. gas and 4.38 lb. NH_3 gas.

The paper is chiefly concerned with geological and chemical questions.

12. An Improved Method and Apparatus for the Removal of Smoke and Fog, Etc. Patented by E. Oades, Wokingham, Eng. *Journal of the Society of Chemical Industry*, vol. xi., p. 233 (1892).

(p. 233.) Two sets of pipes or mains are laid under a roadway provided with suitable traps or gratings, through which air or fog is drawn and conducted to adjoining hearths or fires, etc.

12a. Improved Apparatus for the Purification of Gaseous Fumes, Etc. Patented by M. F. Purcell, Dublin, and G. Purcel, Los Angeles, Cal. *Journal of the Society of Chemical Industry*, vol. xi., p. 1025 (1892).

(p. 1025.) Patent apparatus for purification of gaseous fumes, air, etc. An ordinary exhaust-fan, into the casing of which numerous nozzles are fitted. Water, containing or not suitable substances in solution, is made to impinge on the vanes of the revolving fan, and is converted into mist and takes out all solid particles.

13. Smoke-Consuming Apparatus. A. R. Sennett, *Report of the British Association for the Advancement of Science*, p. 880 (1892).

14. A System of Purifying Smoke from Domestic and Other Fires. Col. E. Dulier, *idem*.

Mixing smoke as it leaves the boiler with a small quantity of steam generated in kitchen-range boilers. The mixed gases rise into an open chamber, the top of which is provided with pipes, placed in the direction of the prevailing wind, through which air passes and cools the gases. At the extreme top, just before entering the air, the gases are met with a spray of water from perforations in a conducting-pipe. The result of this treatment is a washing of the smoke and complete removal of all soot, dust and SO_2.

The amount of steam is small. At the Sloane gardens the expense is ten gallons of water per hour. The apparatus treats the smoke from a large kitchen-range burning 20 lb. coal per hour. The draft is not sensibly impaired (?).

15. The Identity of Lung-Pigment with Soot. J. Wiesner, *Monatsheft*, vol. xiii., p. 371 (1892).

Ueber den mikroskopischen Nachweis der Kohle in ihren verschiedenen Formen und über die Uebereinstimmung des Lungenpigments mit der Russkohle.

In the course of investigations under the microscope Dr. Wiesner has often been puzzled to determine whether small black particles, incapable of other examination, were coal or not. Various bodies are called coal, such as soot, charcoal, lignite, anthracite, and graphite.

In the interest of . . . the microscopic examination of atmospheric dust, in differentiation of writing-characters, etc.

On this occasion the author communicated the results concerning the problem stated, and concerning the pigment in the human lungs. Examination was made of the inks of the characters on papyri, mummy-bands, and the oldest known papers. No difficulty was found with ferro-tanno-gallates, but much with soot and India ink. A mixture of chromic acid and sulphuric acid was made in such proportions that in the reduction of the chromic acid the resulting chrome oxides were held in solution. For this purpose he treated cold concentrated potassium bichromate with excess of

sulphuric acid, and added only so much water as was necessary to keep the separating chromic acid in solution.

The amount of sulphuric acid added should be just enough to keep in solution the whole of the chromium oxides separated from the chromic acid, but an excess of H_2SO_4, according to Dr. Wiesner's experience, is not injurious, nor is the potassium bisulphate. All cells are destroyed by this reagent, and carbon-particles are unchanged for a long time.

For years the author had noticed that soot is but little attacked by chromo-sulphuric acid. The little carbon-particles in the soot were in weeks or months hardly affected while the tarry mass went into solution. The particles of soot after a long time were unaltered, suspended in the liquid, and this fact led to a method for distinguishing soot in writing-inks. Part of a letter is cut out of the MS., placed upon platinum foil, and treated with chromo-sulphuric acid. The paper will entirely disappear, leaving only the writing-substance. If the fluid be removed and this residue heated on the foil it burns, leaving behind an ash, and proving carbon.

By this reagent lignite can be distinguished from charcoal, soot, and graphite.

Dr. Wiesner sets forth the results of a microscopical examination of the principal varieties of coal:

Amorphous Carbon.—The first experiments were with charcoal. No change was observed after it had been long exposed to the action of chromo-sulphuric acid, but the solution which came away from it was greenish.

Soot was not changed for a long time, but a slightly greenish tinge was imparted to the reagent, and the soot-particles disappeared after weeks.

Amorphous carbon is therefore in a state of extremely fine division.

Not infrequently one hears of transparent carbon.

This arises from an erroneous interpretation of F. Schulza's observation (*Nat. Vers.*, Gotha, 1851). The finest breath of soot on a glass plate looks translucent, but under the microscope it consists of isolated opaque points. Either of two explanations is possible. Either the very thin coal particles are brown or the reagent has by oxidation produced another compound which is brown.

Soot.—A layer of soot, not too thin, on a glass plate, under a high microscopic power shows two substances: one small black opaque points, and the other fine colorless, yellowish, or brownish objects lying together but more or less coalescent. If treated with Dammarlac, or oil of cedar, all but the black opaque particles disappear.

The atmospheric soot presents another aspect. Of course the fluid constituents are wanting, but several different kinds of solid bodies are present: small, apparently homogeneous, soot-particles; dendritic aggregates of them; black and brown fragments, generally of irregular, seldom of rounded form. The black fragments consist of black soot-kernels more or less united, yet under the highest magnifying power the cementing substance is not visible. The brown fragments are more compact and consist of a brown matrix in which small black soot-grains are imbedded. The matrix is derived from the liquid components.

If this soot be subjected to treatment in cedar oil, the large fragments disintegrate gradually into small roundish black balls, and dissolve finally into countless extremely small grains, which are identical with the above-named black bodies. In chromic acid, under the microscope, the soot remains some time before the same disintegration is effected. After weeks of subjection to this acid the particles are still visible, but smaller. But it is not possible to say from microscopic observation whether they have been partially dissolved or only still further disintegrated. At last after months they disappear entirely. [Then it is probable they were dissolving.—ED.] Atmospheric soot contains, besides the coal-particles and cement, also

masses of small bodies derived from the material used to produce it. Iron was thus found.

Brown Coal (*Lignite*).—However variously these substances appear to the eye, in the microscope they all agree in that the powder is quickly changed by chromic acid into a yellowish and finally colorless mass, which for the most part represents a skeleton or nexus consisting, as the reactions teach us, of cellulose. For if this detritus be washed carefully with water it is soluble in cupric oxide-ammonia, and becomes violet with chlor-zinc-iodine solution.

Gas is evolved from powdered brown coal by chromic acid and in a few hours the solution becomes green.

Anthracite.—If finely powdered anthracite be covered by Cr_2O_5 in a test-tube, after some days or weeks the color of the liquid will be changed into brown or green, according to its quality.

Welsh anthracite took eight days to show this change of color and behaved like pure carbon.

Under the microscope without exception the greater part of the substance consisted of black opaque particles; but there were also some brown grains, the easier to find the greater the proportion of oxidizable substances (not mineral impurities) it contained.

Such brown bodies were not found in brown coal, but nevertheless they may be there, as they represent a more advanced state of carbonization, in which either the entire cellulose of the plants from which the anthracite was produced is transformed into carbon compounds, or so little is present that the reagent has destroyed it.

Bituminous Coal (*Stein Kohle*).—Careful microscopic research proves that the variety last mentioned and this one are connected together by transitions.

Pulverized bituminous coal is rather quickly oxidized by Cr_2O_5; less so than lignite, but more so than anthracite.

Lignite dissolves without residue; the greater part of anthracite is unaffected; bituminous coal leaves a small residue, which behaves like the residue of anthracite, both chemically and under the microscope. The brown or reddish brown parts are divided into:

1. Bitumens (Harze)—*i. e.*, fusible bodies soluble in bitumen-solvents.
2. Bodies which react exactly like lignite to chromic acid.
3. Bodies which correspond exactly with the brown or reddish brown transparent anthracite grains in appearance and also in their behavior to Cr_2O_5. 1 and 3 are homogeneous, while 2 is often not so. The microscopic examination shows that bituminous coal is an intimate mixture of lignite and anthracite. Anthracite appears to predominate.

Charcoal.—As is well known, the percentage of carbon in a charcoal depends upon the temperature at which it is produced. At a comparatively low temperature there is produced the so-called red charcoal, which is advantageously used in the manufacture of gunpowder. At a high temperature black charcoal is produced, which is richer in carbon.

Powdered red charcoal reacts to Cr_2O_5 like lignite; black charcoal like anthracite.

Both red and black charcoal possess exactly the texture of wood. The outer cell-membranes of the former appear under the microscope brown, in the latter black.

Graphite.—Graphite powder covered by chromic acid was examined under the microscope for days, and indeed for two months, without the detection of the least appearance of diminution or solution even in the smallest particles. But there is an oxidizable constituent present, as the change of color of the supernatant fluid proves. It is hard to distinguish from soot, though it is not easy to reduce graphite

to so fine a state of division. In combustibility, soot and charcoal-dust burn instantly on platinum foil; lignite, bituminous, and anthracite burn more slowly, but graphite is almost incombustible.

The following is the author's conclusion as to the identity of black lung-pigment and soot:

Virchow's "lung black" has been examined. Koschlakoff and Virchow have written on the subject. Traube proved that splinters of charcoal could enter the alveolæ. Knauff believed the pigment was composed of soot, from his experiments on dogs allowed to live in a smoky atmosphere. On killing them and examining their lungs the black lung-pigment was found to be indistinguishable from soot, but it was objected that this material might be the carbonization of extravasated blood.

Hoppe-Sayler says the pigments of the eyes, skin, melanitic carcinoma, hair, feathers, fish-bone, etc., are easily decomposed by treatment with alkali-solution or chlorine. But in the lungs and bronchial ramifications is a body of perfect black color which is insoluble in potash lye, and chlorine, and is therefore carbon.

From examination under the microscope of strips of lung-material with melanine spots, furnished by Prof. Sig. Exner, and from the behavior of this material when treated with Cr_2O_5, it was demonstrated that the pigment-particles of the lungs and of the sputum were of the same origin, and that they reacted to Cr_2O_5 just as the brown particles of atmospheric soot.

The black lung-pigment was compared with the black material in the discharge from the nose of inhabitants of smoky cities, and found to correspond.

Résumé.—1. The essential constituent of lignite is brown, and transparent; is made colorless by Cr_2O_5; and leaves, after treatment, a histologically determinable net-work of cellulose.

2. All other forms of carbon (anthracite, bituminous coal, charcoal, soot, and graphite) contain usually small quantities of a substance easily oxidized by Cr_2O_5, which turns it brown, and at last green. The residue is unalterable by long treatment with this reagent.

3. Anthracite is practically unalterable by Cr_2O_5, but contains a dark brown transparent body which is slowly oxidized by Cr_2O_5, leaving no cellulose.

4. Bituminous coal behaves under the microscope like a mixture of lignite and anthracite, and leaves a small residue of cellulose when treated with Cr_2O_5.

5. So-called red charcoal is thoroughly decomposed by Cr_2O_5, and, in a certain stage of the decomposition, cellulose in the form of wood-structure remains.

6. Soot freshly deposited on glass consists of small black carbon-particles which after weeks of treatment by Cr_2O_5 remain, and of fluid drops of oily nature. Atmospheric soot consists in part of fine carbon-particles, partly of aggregates of small particles either dendritic or irregular in form; or, less frequently, round fragments which either show black grains in a brown matrix or appear simply as more or less loose aggregates of black grains.

7. Black lung-pigment, which during the lifetime collects in every human lung, and especially in the interlobular connective tissues of the lung, and of which the true nature has not hitherto been sufficiently explained, consists of soot in the form of large or small dark bodies, which appear as fine, point-like grains, and after weeks of subjection to chromic acid show no alteration.

Melanines distinguish themselves from this pigment by the ease with which they are decomposed after a few minutes of treatment by chromic acid.

Note.—After this work was completed Dr. Wiesner received from Prof. Liebur chemically pure carbon prepared from soot obtained from a gas-flame on a cool porcelain vessel, and purified by heating to redness in chlorine, nitrogen and hydrogen. This substance contained 99.3 per cent. carbon.

This body reacted very nearly like the black residues of anthracite and other coals described above, which were called amorphous carbon; but probably on account of its extreme fineness it was notably easier to oxidize by cold Cr_2O_3 than these residues.

Like the bodies described above as pure carbon, it is much more rapidly oxidized by chromic acid even under the boiling-point of water. Warmed over the open flame, the oxidation takes place with visible disengagement of gas.

16. AUTOMATIC APPLIANCE FOR RECORDING THE PRESENCE AND DENSITY OF BLACK SMOKE IN FACTORY CHIMNEYS. William Thomson, *Journal of the Society of Chemical Industry*, vol. xi., p. 12 (1892).

Two brass tubes about 5 ft. long, one of 1⅛-in. and the other of ⅝-in. internal diameter, are placed one within the other. A slit is made through both tubes lengthwise to within 3 in. of end. Another cut is made at termination of slit at right angles to first. A semicircular plate is made to join both tubes at the end of the 3-in. cut. Paper is made to move across the slit at the rate of 4 in. per hour and a copper tube inside the brass tube conveys cold water to keep the paper cool, it being found that smoke will not deposit so easily on a hot as on a cool surface.

The apparatus is then put into the chimney or flue, and the clock-work so attached as to keep the paper moving at a uniform rate of speed.

17. MODERN LEGISLATION IN RESTRAINT OF THE EMISSION OF NOXIOUS GASES FROM MANUFACTURING OPERATIONS. A. E. Fletcher, H. M. Chief Inspector under the Alkali Act, *Journal of the Society of Chemical Industry*, vol. xi., p. 120 (1892).

The Alkali-Regulation Act of 1863 was a new departure. It originally only dealt with hydrochloric acid. Its first effect was to heighten chimneys. This failing, the Gossage condensation-towers were tried. Operation nearly perfect. Standard condensation of 95 per cent. accepted by manufacturers. Not only acid character of furnace-gases was determined, but, by means of anemometer invented for the purpose, the volume escaping. Collapsable aspirator of vulcanized rubber used to take samples and absorbent of gas introduced into it.

Two-tenths grain of HCl in a cu. ft. of air, and not more than 5 per cent. of the total gas produced allowed to escape, together formed the restrictive law.

The consumption of a million tons annually in St. Helen's and Widnes made the consequent SO_3 from this and from the copper and glass works overshadow the evil which the Alkali Act sought to remedy.

In 1881 an amended Act superseding previous Acts was passed to adopt "the best practicable means for preventing the discharge into the atmosphere of all noxious or offensive gases evolved in such works." (Discussion on pp. 120 and 309 as to method of working of the two Acts.)

18. SMOKE-PREVENTION. Report of a Special Committee of the Engineers' Club, St. Louis. *Journal of the Association of Engineering Societies*, vol. xi., p. 291 (1892).

Detailed statement of the process of burning bituminous coal, with the changes which occur.

The great offenders as smoke-producers in large cities are boiler plants. Of 78 consumers in St. Louis, but 7 were using smoke-preventing apparatus. Nineteen have used some kind of smoke-preventers but have discarded them for various reasons. One found his smoke-consumer consuming one-eighth more coal than the common furnace.

The following is a condensation of Parts VI, VII and IX of the report:

VI. Requirements for a successful smoke-consumer.

1. Efficiency: (*a*) Development of high temperature; (*b*) regularity of action; (*c*) not easily got out of order; (*d*) small increase to operation.

2. Capacity. Must be efficient when boiler is working to full capacity.

3. General applicability : (*a*) Ready adjustment ; (*b*) application in limited space; (*c*) low cost ; (*d*) few repairs ; (*e*) no injury to boilers, etc.

VII. Classification of the important types of smoke-preventing devices already proposed and the principles on which they depend.

A. Steam-jets to introduce air into the fire-place.
B. Fire-brick arches or checker-work.
C. Hollow walls for pre-heating the air.
D. Coking arches or chambers.
E. Double combustion.
F. Downward-draft furnaces.
G. Automatic stokers.

IX. Conclusions and Recommendations.

This deals with (1) a determination of the practical limits within which smoke emission may be confined, and (2) a determination of the applicability of various devices to the purpose intended.

Recommendations are as to legislation and the diffusion among the public of information as to the facts which may aid them in using smokeless fuel.

Various circulars and ordinances in Cincinnati and Pittsburgh.

19. THE COMBUSTION OF COAL IN HOUSE-FIRES. J. B. Cohen, Ph.D., and G. Hefford, A.I.C., *Journal of the Society of Chemical Industry*, vol. xii., p. 121 (1893).

The amount of sulphur in coal is of importance.

SO_2 in air oxidizes to H_2SO_4 and attacks stone, brick, and respiratory organs.

First smoke-abatement meeting, Leeds, 1842. House-fire principal cause of trouble. Amount consumed so small that it does not pay householder to alter systems of burning, which are very bad.

Corporation sewage-works at Holt (town near Manchester) use as fuel almost exclusively cinders from household fires.

1855, Delezenne estimated unconsumed carbon as 5 per cent. of the total weight. Very black smoke, 0.1 per cent. of amount burned.

Analysis of Soot.

1. Manchester Air-Analysis Committee. Out-door deposit.
2. Roberts-Austen. Aspirated from flue.
3. Cohen-Hefford. Deposit in flue used.
4. Deposit in another flue.

	1	2	3	4
Carbon,	39	86–94	68.5	75.3
Hydrocarbons, etc.,	14.3	(H) 3.3–5.2	(H) 4.4	3.9
Sulphuric acid,	4.33	. .	(S) 4.8	3.2
Mineral matter,	36.67	8–9.7	22.7	16.3

	House-fires.	Angus Smith. Black Smoke.	Cohen and Hefford. House-fire.
In flue-gases, grams per 100 liters,	0– 0.09	0.043	0.03
Per cent. C burnt (at 1.2 per cent. CO_2 in fuel-gases),	0–13	. . .	5.09
Deposited in chimney at 100 of coal,	0.61–2.25	. . .	. . .

Bailey showed that of sulphur in coal 53 to 55 per cent. escaped into air, 4.8 to 5.4 per cent. remained in the clinker, and 39.6 to 42.3 per cent. disappeared (!).

Angus Smith finds from coal containing 2 per cent. S, 0.23 g. SO_4 in 100 liters. From a direct determination of SO_2 in black smoke he found 0.07 SO_2 in 100 liters.

Discoloration of Silver Articles.—This during foggy weather is attributed to formation of Ag_2S from S compounds in the air.

$AgSO_2$ is in air; this was tried, but only produced blackening in presence of soot.

Air filtered through plug produced less effect than not filtered. H_2S is in very small quantity in air, but must be considered.

Mr. Thomson remarked that silver was blackened by HCl vapors. On repeating experiment it appeared that pure silver was not thus blackened, but alloys of Ag and Cu. The acid dissolves out the Cu as $CuCl_2$, which is later decomposed, leaving a black film of Cu on the silver.

In discussion the chairman (Mr. T. Fairley) remarked that leading the acid gases through alkaline solution was not sufficient to absorb them, but that they must be violently agitated in presence of the solution.

Thomson proved that HCl in the light produced more effect than H_2S.

If a glass plate moistened with glycerine were exposed much more soot was collected than from snow.

Dr. Lewkowitsch thought organic sulphur compounds were to be studied. He thought producer-gas was the best method to abate the smoke nuisance.

Prof. Smithells alluded to the doctrine that unburnt carbon and SO_2 furnished the air with valuable antiseptic media of infinite value to congested centers of population. He disbelieved it.

20. TOWN SMOKE. Discussion before the Society of Chemical Industry. *Journal of the Society of Chemical Industry*, vol. xii., p. 325 (1893).

Mr. Ivan Lewinstein, the Chairman, stated that the deficiency of light on Sundays in the Hulme district being as great as on week-days proved that the pollution of the atmosphere was to a large extent due to domestic fires.

Mr. Grimshaw said manufactories contributed about 20 per cent. of smoke-pollution in large towns.

Mr. Teny said the alternatives were to burn either gas, anthracite or ordinary coal in an improved grate. He thought the last was the only solution.

The hydrocarbons produced and voided through the chimneys were paraffines, not benzenes.

21. RAUCHBESCHÄDIGUNG IN DEM VON TIELE-WINCKLER'SCHEN FORSTREVIERE MYSLOWITZ-KATTOWITZ, INSBESONDERE ERMITTLUNG, BEWERTHUNG UND VERTHEILUNG DES RAUCHSCHADENS. Carl Reuss, Herzogl. Anhalt. Regier. und Forstrath zu Dessau. 4to, 236 pp., with two charts. J. Jäger u. Sohn, Goslar (1893).

Introduction.— . . . The present enormous use of coal and constantly increasing extension of chemical-works, furnaces, and other industries is commencing to expose injuries which cannot be overlooked. . . . "One can note how works hide their processes of manufacture, the kind and quantity of the materials employed, in order to render the recognition of the kind and amount of damage more difficult."

The precautions required by law to restrict the emission of injurious products in the air are evaded, etc.

On the other hand, gardens are purposely set out with expensive ornamental flowers, unsuited to the climate, and which have no chance of prospering, in order to profit by the damages for destruction by smoke.

The subject has reached an importance which justifies its consideration as a separate science.

Metallurgist's report. By von Skal. Queries: 1. What are the injurious components in the smoke? 2. To what works is the damage traceable? 3. In what proportion do they share responsibility for the damage?

As to the injurious components of the smoke, the opinion of Dr. v. Schroeder, of Tharand, is authoritative. The metallic salts insoluble in water produce no injurious effect, and those soluble in water and arsenious acid only a very slight one. But the injurious constituents are SO_2 and HCl, and especially the first.

. . . The SO_2, which has been recognized as the commonest cause of the damage caused by chimney-smoke, is due to the sulphur in the coal and to the zinc- and lead-ores treated in the smelting-works. H_2SO_4 and HCl were observed only in the minutest traces in the chimney-gases, and not to be compared with the very large proportions of SO_2.

The percentage of S in the coals varies so much that v. Skal assumes, on Muck's authority (*Elementarbuch der Steinkohlenchemie*, p. 43), 1 per cent. in all the coals, which is often exceeded and seldom not reached.

Forestry Report by Reuss.—Reuss agrees that the principal cause of damage is SO_2, but observes that he has frequently had occasion to note in compost manufactories very evident signs of injury through HFl, and in this connection gives the method of Herrn Schumacher for the determination of HFl in vegetation.

25 g. of the dried and pulverized vegetable matter is treated with 5–7 g. K, Na carbonate and water in a nickel dish and evaporated to dryness.

This is then coked in a platinum dish and the residue leached out with hot water and filtered. The carbonized particles on the filter are dried and incinerated while the filtrate is being evaporated. The ash and salt residue are then treated with 5–7 g. more K, Na carbonate, thoroughly dried in a platinum dish and brought to quiet fusion over the blast-lamp, until the mass shows no bubbles. The melted mass is several times boiled with distilled water, and washed with boiling water, the filtrate treated with a little tincture of litmus, and then with dilute HNO_3 till it assumes a violet color; then evaporated in a platinum dish, at the end with repeated additions of Schafgot's solution, whereby the SiO_2 separates and is twice filtered and washed. After all the solutions have been united and again evaporated the remainder of the SiO_2 (after the expulsion of the $(NH_3)_2$ (CO_2) is precipitated by zinc oxide-ammonia, filtered, and the filtrate, now entirely free of SiO_2, precipitated by $CaCl_2$ solution and heated till all the CO_2 is expelled. The remaining precipitate is filtered, thoroughly washed, dried and heated to redness, then treated with excess of somewhat dilute acetic acid, evaporated on the steam-bath till every trace of vinegar odor has disappeared, dissolved in hot water, filtered, and the residue washed with hot water. It is then dried, and heated to redness in a platinum crucible and covered with excess of concentrated H_2SO_4 to which a drop or two of water had been added, after a tared glass plate has been placed as a cover on the crucible. The crucible is then heated for several hours over a small flame at some distance but finally close to the latter until no further action of the vapor on the glass plate is observed. The cooled and cleaned glass plate is then dried and after 15 minutes' cooling is again weighed over H_2SO_4.

The final etching of the glass plate by HFl and loss of weight is calculated as Fl in such manner that 2 parts by weight of loss in the glass are assumed as 5 parts of Fl, which relation was reached by experiments on pure $CaFl_2$. . . .

In this manner in 1888 and 1891 I demonstrated the damage to vegetation by the HFl escaping from the phosphate-works in Vienenburg, etc. . . .

The acute injury is apparent when the plants or their dead parts appear generally red to reddish brown. Little by little, through weathering, this color changes, depending upon the tenderness of the leaves, from a light or darker brown to black. Young leaves and tendrils that have been completely killed, crumple up and seem withered, and retain for a time a greenish color which only later is transformed to blackish.

When the injury is slight the leaves of the deciduous trees become dirty, pale;

bleach, and remain sickly and small: take on too soon a weathered, dirty autumn coloring, and soon wither.

The evergreens behave similarly. At the commencement of the injury the needles, sometimes the older, become pale, strangely colored, dirty green, first on the upper side, which is more exposed to the smoke. Little by little all the needles become sickly, die and fall off, beginning with the older.

By continued smoking and increasing weakness of the tree the younger to the youngest plants die, and simple dry twigs and tops are observed. After a while individual trees are killed and bring about patches in the woods, which finally unite and produce barrens.

Even with this the smoke-injury is not done. The ground is made to share the injury in no small degree. Even at the beginning of the formation of gaps a growth of grass appears which rapidly consumes the provision of the humus. As usual in uncovered ground, the poorer berry-plants follow, and finally the heather, until by continued smoke-devastation even this disappears and the ground is the prey of wasting floods and dissipating winds.

With the appearance of chronic injury to the leaf there is generally noticed a blackish coloration of the bark, which is partly due directly to the smoke, and partly to the increased destruction and more rapid weathering of the outer epidermis. Also, an unusual collection of fallen undecomposed needles on the ground of evergreen forests may be taken as a tolerably sure sign of considerable injury by smoke.

It is gratifying for the corroboration of the visual test when this can be restricted to one kind of tree, since thereby the confusing differences due to the varying powers of resistance of different kinds of trees are avoided.

. . . Frequently alongside of perfectly sound or at least little injured trees are found very seriously affected growths and those nearly dead. The injury of a tract can never be denied because of individual sound trees found within it, but must be judged by the general condition of all the plants within it, with special attention to all observed injuries.

The degree of injury of a tract is not to be determined by the average of the observed injuries but by the most severely injured, which can be recognized with certainty.

As a tree for the investigation the fir was used because it was almost everywhere present, and owing to the needles remaining long in normal condition it is suited to make even lighter injuries apparent to the eye. For the rapid and exact definition of the injury of a tract the author grades the degrees of injury as follows:

	Injury
Needles and stem healthy,	0
Older needles pale, dirty green, sickly,	1
Needles of older trees dead and fallen needles sparse,	2
Occasional twigs without needles, and dead from smoke,	3
Majority of twigs dry, the tree nearly dead,	4
Occasional trees dead from smoke,	5
Large number of trees dead; gaps in the tract,	6
Entire tract destroyed by smoke with exception of a few trees,	7
Ground vegetation nearly killed by smoke,	8
Ground vegetation entirely killed,	9
Land barren and wasted by water and wind,	10

In the tracts containing trees 40 or more years old the degree of injury is 3 and more. In young plantations the injury is less noticeable. . . .

Chemical Examination.—It is desirable to demonstrate by careful chemical analysis the kind and extent of the damage, and the fact that the whole region has been in-

jured by the SO_2 with which it is infected. The examination was confined to the firs. In October, 1891, ten tests were made, distributed evenly over the entire district. The needles of the 1891 specimens were carefully separated from the older and both separately tested for H_2SO_4. In a table the older needles are shown to contain more H_2SO_4 than the younger, running from 0.53 to 0.87 in the older and from 0.44 to 0.74 in the younger.

The normal percentage of H_2SO_4 for fir-needles is 0.2 in the Harz and is assumed as the same in the Myslowitz-Kattowitz region, though it was not possible to find a specimen free from smoke-poison to establish the fact. 30 km. from Kattowitz the fir-needles from a place somewhat affected by locomotive smoke gave for the older needles 0.23 and for the younger 0.14; or 0.19 for an average, which confirms the results in the Harz.

In the Myslowitz-Kattowitz district the highest percentage of H_2SO_4 is four times, and the lowest twice, the normal.

The explanation of the less percentage of H_2SO_4 in young than in old needles is that the former have not been so long subjected to the action of smoke.

The development of the needles begins early in May and ends about the beginning of July. The average life of the young needles was about one month. In one month the needles take up 51 per cent., and in five months 71 per cent. of the H_2SO_4 content of the old needles.

(Tables and discussion of the method of taxing the damage.)

4. *Distribution of the Damage Among Particular Works.*—The task of the expert is to discover the extent to which each works is responsible for the damage.

The amount of SO_2 is not the only criterion of the amount of damage done. Two regions might be equally exposed to smoke and one suffer much more than the other. The height of the chimney-stacks is about 40 m. (131 ft.) In only two cases were the stacks 100 m. (328 ft.) high. It was expected that the higher chimneys would lessen the amount of damage by allowing the acid gases to become more dilute before they reached the vegetation. Experience teaches that these assumptions are only realized to a moderate degree.

In spite of the unquestionable benefits of the apparatus generally associated with stacks (dust chambers, etc.), and the fact that the nearby vegetation is not so much injured from a high as from a low stack, there is some damage done with high stacks to even the nearest vegetation, and remote vegetation is reached by smoke from high stacks which would not be injured otherwise.

22. SMOKE-ABATEMENT WITH REFERENCE TO STEAM-BOILER FURNACES. Geo. Caruthers Thomson, F. C. S. *Proceedings of the Philosophical Society of Glasgow*, vol. xxvi., p. 148 (1894–95).

Bituminous coal was introduced as a fuel in the Thirteenth Century, but in 1306 a decree was passed forbidding its use. Many authorities are cited against the use of coal from this time on, including Count Rumford. The police and other regulations are given, with the percentages of punishment for their infraction.

Dr. Wm. Wallace, in a short paper read before this Society in 1880, shows that part of the sulphur is in pyrite and part in an organic compound. He estimates only half of the content to be volatile. . . . The area of the outlet at the top of the chimney should not be less than the area of the main flue. . . . Mr. Alf. E. Fletcher has shown that in some cases, when black smoke was emitted, CO was present, but when the chimney-top was clear no CO was emitted. R. Irvine estimates soot as 3 per cent. of all the smoke; Cohen and Hefford give 5 per cent. . . . According to G. Gruner, 1892, the fires of Dresden deposit about 4,800 cu. m., or nearly 1,000 tons, of soot, equal to 20 kg. of soot daily on each sq. km., 0.69 grain per sq. yd. . . . Mr. J. Aitken, F.R.S., says: "If we could get a fuel

without sulphur we should get rid of a powerful element in city fogs." The sulphur compounds rather than soot are the cause of fogs.

Siegfried Hamburger, in a paper on Injury to Vegetation, etc. (*Journal of the Society of Chemical Industry*, vol. iii., pp. 203, 343 (1884), quotes from Dr. Angus Smith substantially as follows:

In a part of London where coal is in the main only used for domestic purposes I found 730 grains SO_3 in 1,000,000 cu. ft. of air. In Manchester 1,098 grains.

Hamburger found in St. Helens 1,260 grains. Fletcher (1879) calculates that the gases escaping into the air at St. Helens per week contain:

Fire-gases, ...	800 tons SO_2
Copper-works, ...	380 tons SO_2
Glass-works, ...	180 tons SO_2
Alkali-works, ...	25 tons HCl

The inspectors under the Alkali Act sometimes find a larger quantity of sulphuric anhydride escapes from coal-combustion than is allowed to escape from sulphuric acid works.

23. THE EXTINCTIVE ATMOSPHERES PRODUCED BY FLAMES. Prof. Clowes, D.Sc., and M. E. Feilmann, B.Sc., *Journal of the Society of Chemical Industry*, vol. xiv., p. 345 (1895).

This paper treats of careful experiments to determine the composition of the atmospheres which cease to support flames of various combustibles.

24. UEBER DIE BESTIMMUNG VON SCHWEFLIGER SÄURE UND SCHWEFELSÄURE IN DEN VERBRENNUNGSPRODUKTEN DES LEUCHTGASES.

ON THE DETERMINATION OF SULPHUROUS AND SULPHURIC ACID IN THE COMBUSTION-PRODUCTS OF ILLUMINATING-GAS. Uno Callan, *Zeitschrift für analytische Chemie*, vol. xxxiv., p. 148 (1895).

Proves that the greater part of the sulphur on burning lighting-gas is transformed into SO_2, and 93.3 per cent. of this SO_2 was changed in the absorption-liquid to H_2SO_4.

25. THE ALLEGED ESCAPE OF CARBONIC OXIDE AND UNCONSUMED CARBON FROM COAL-GAS FLAME. Lewis T. Wright, *Journal of Gas Lighting*, vol. lxvi., p. 1023 (1895).

The writer concludes from a number of tests that there is no escape of CO or of unconsumed gases from the gas-flames of Auer (Welsbach) or other gas lights.

26. RAUCHBESCHÄDIGUNG IN DEM GRÄFLICH V. TIELE-WINCKLER'SCHEN FORSTREVIERE MYSLOWITZ-KATTOWITZ. NACHTRAG ZU DEM WERKE GLEICHER BEZEICHNUNG V. JAHRE 1893 UND ENTGEGNUNG AUF DIE SCHRIFT, "WALDSCHADEN IM OBERSCHLESISCHEN INDUSTRIEBEZIRK, EINE RECHTFERTIGUNG DER INDUSTRIE GEGEN FOLGENSCHWERE FALSCHE ANSCHULIDIGUNGEN," VON PROFESSOR DR. B. BORGGREVE; SOWIE WIDERLEGUNG EINIGER VON ANDERER SEITE GEGEN MEIN WERK "RAUCHBESCHÄDIGUNG, ETC." (1893) ERHOBENEN EINWÄNDE, MIT EINER KARTE. Carl Reuss, Herzöglich Anhaltischem Oberforstrath. J. Jäger und Sohn, Goslar (1896).

This is a bitter polemic directed at Herrn Borggreve's attack on his former work. Accompanying it is a map of a territory 60 km. E. and W., and 50 km. N. and S., of a part of Upper Silesia which is interesting as showing Reuss's results in hundredths of a per cent. of H_2SO_4 for the vegetations of all parts. The determinations vary from 0.21 per cent. in regions where there are few industrial works (*i. e.*, between Kobier and Mezerzitz), to 80 in the vicinity of the most densely occupied industrial district (between Myslowitz and Kattowitz).

At a distance of 200 m. (656 ft.), the advantage of the high stack ceases to be apparent. In damp, still, heavy air the smoke with its SO_2, which is heavier than air, falls rapidly to the ground. When the wind blows continually one may observe the smoke escaping from the high stack gradually sinking and holding together for considerable distances; so that it does not suffer any unusual dilution. If one observe the smoke poured out from chimneys of different heights, at first that of each chimney can be separated, but in from 100 to 1,000 m. (depending upon the differences in height) the different masses behave as if they exerted an attraction on each other and soon mingle into a thick cloud which pursues its further course as a single mass. From these facts the difference in height of 60 m. (197 ft.) does not produce a measurable difference in the amount of injury.

The amount of SO_2 which reaches the vegetation will depend (1) on the amount of acid which escapes from the chimneys; (2) on the distance of the latter from the vegetation; (3) on the direction of the wind.

The injury is increased by dampness and lessened by dryness.

The vegetation can stand a certain amount of acid gases without injury. Beyond this amount it suffers. (Tables, and a map of 3,000 sq. km. of Upper Silesia, with figures indicating the number of hundredths per cent. H_2SO_4 found in the vegetation of the different parts.)

27. Notes on Poisoning by Carbonic Oxide. Douglas Herman, *Journal of the Society of Chemical Industry*, vol. xv., p. 854 (1896).

The author found mice, cat and rats died in a stable 50 yd. away from produce-plant. Communication only through loose soil. Mice are very susceptible to CO. With man at rest it takes about 20 times as long for a man as for a mouse to be affected. The first indication of poisoning is a dizzy, drunken feeling. Cold at extremities. Action of CO and alcohol similar in withdrawing O from the blood, but whereas alcohol stimulates the heart and provides to a certain degree the antidote CO does not. Affinity of CO for hæmoglobin is strong—250 times greater than that of oxygen.

28. The Combustion of Coal and Gas in House Fires. J. B. Cohen and G. H. Russell, *Journal of the Society of Chemical Industry*, vol. xv., p. 86 (1896).

The average percentage of soot from eight good Yorkshire, two Durham, and two Wigan coals amounted to 6.5 per cent. of the carbon consumed.

The rest of this elaborate paper concerns the evolution of CO, CO_2, and the heating effects; the comparative cost of gas and of coal fires.

29. The Determination of Sulphurous and Sulphuric Acids in the Products of Combustion of Illuminating-Gas. M. Dennstedt and C. Ahrens, *Zeitschrift für Analytische Chemie*, vol. xxxv., p. 1 (1896).

By a series of elaborate experiments the authors assert the error of Uno Collan that the greater part of the sulphur in the ordinary as well as in the non-luminant gas-flame burns to SO_2. Their tables give 88.27 and 81.90 per cent. SO_2 in a very luminous flame and 62.55 in a blue flame; to 10.73, 18.20 and 37.45 per cent. SO_3, respectively.

30. A Method of Estimating the Weight of Solid Matter in the Air. J. B. Cohen, Ph.D., *Journal of the Society of Chemical Industry*, vol. xvi., p. 411 (1897).

In an experiment at Leeds the author roughly appraised the amount at about 1 mg. in 100 cu. feet.

The first method by aspirating the air, using a Beckwith fan, and collecting dust on a glass plate smeared with glycerine, was found unsatisfactory.

The second method was by filtering a small and more carefully measured volume of air, and weighing the solid matter as before. The author employed two bags

with an open zig-zag tube coated inside with vaseline. Experiments were made to determine if the passage of the air-current caused the vaseline to lose weight.

The result of five hours' aspiration of cotton-filtered air showed a loss at ordinary temperature of 1 mg.; and in another experiment of six hours, 0.2 mg.

With deduction of this loss 100 cu. ft. of air was found to contain 1.36 mg. solid matter. In Leeds the average is 1.2 mg. per 100 cu. ft.

31. VERUNREINIGUNG DER LUFT IN DEN REINIGUNGS- UND REGENERIRHÄUSERN DER GASANSTALTEN. H. Drehschmidt, *Journal für Gasbeleuchtung und Wasserversorgung*, vol. xl., p. 517 (1897).

It has been often asserted that the workmen in cleaning- and regenerating-works have been injured by inhaling the air in such places, but the spectroscopic examination of their blood has not confirmed this supposition. The police of Berlin required investigations to be made. Dr. Hans Wolf, Assistant at the Gas Works Laboratory, has done most of the work.

The poisonous ingredients are ammonia, hydrocyanic acid, hydrogen sulphide, carbon disulphide, and other sulphur compounds of carbon. Ammonia is eliminated by the dry-cleaning process to 1 cc. in 100 cu. m. The other gases and vapors, excepting the carbon oxides, are almost completely withdrawn by the dry-cleaning. The hydrated iron of the cleaning-apparatus might hold the noxious gases so feebly that they would be disengaged on taking the material out, but not H_2S, etc.

CO_2 can only appear on the emptying of the cleanser.

Hydrocyanic Acid.—The cleaned substance, if subjected only once or twice to the process of the cleanser and spread out on the regenerator floor, contained 0.000066 and 0.00014 vol. per cent. HCy. After having been used 13 or 14 times 0.00012 and 0.00012 vol. per cent. HCy. As more HCy was proved to exist in the older masses, the amount in the air was determined when the charge had lain a considerable time on the floor of the regenerator. 0.00002 vol. per cent. HCy was obtained. No case has been found where the breathing of the HCy in the air has proved injurious. The author does not believe any injury from this cause has occurred to workmen.

Ammonia.—400 to 600 liters of air were passed through normal H_2SO_4 for the test. When the mass had lain some time on the floor of the regenerator the air contained 0.00002 vol. per cent. NH_3.

When first brought to the regenerator, 0.00004 vol. per cent.

On emptying the cleaning-boxes, 0.00041 vol. per cent.

Hydrogen Sulphide Gas.—A qualitative test with moist lead-acetate paper gave hardly visible indications of this poison.

Carbon Monoxide.—This was collected in the cleaning-vessels.

The emptying lasted two hours. The samples of air were passed through potassium solution and then through red-hot platinum capillaries, and the resulting CO_2 determined by baryta-water. In the samples examined were found 0.006, 0.027, 0.038, 0.032 vol. per cent. of CO.

No symptoms of poisoning appear (according to W. Hempel) unless the CO reaches 0.043 per cent. of the volume of air containing it.

The results prove that the work in the cleaning- and regenerating-houses, under ordinary circumstances and with familiar precautions, is not injurious to those undertaking it.

32. VEGETATIONSSCHÄDEN DURCH GASAUSSTRÖMUNG. Dr. Otto Pfeiffer, *Journal für Gasbeleuchtung und Wasserversorgung*, vol. xli., p. 137 (1898).

It is well known that the trees of large cities are injured or killed by gas. The lindens of the street in Berlin to which they give the name are an example.

In other cities the same state of things exists. It was natural that the leakage from the network of illuminating-gas pipes was first blamed. This has also been proved

by a number of experiments. The most important experiments were made by the Berlin College of Magistrates in 1871 in the botanical gardens and also in private gardens, according to the report of Virchow. The subjects of experiment were maple, linden, plantain, silver-poplar, acacia, etc., against the roots of which during several months to a year measured quantities of illuminating-gas were constantly led. By these and similar experiments (especially by those of V. Böhm) the poison symptoms were determined, beginning with the withering and falling of the leaves, while the rootlets were completely decayed and killed; and Kny observed a curious bluish color in sections of roots with diameters up to the thickness of a finger, increasing in strength from the center to the periphery: which indicated that the poison entered the growing roots with the nutritive material, and not through the bark of the older roots. From this the poison from illuminating-gas must be accepted as a fact.

Freytag thought clean gas free of tarry products was not injurious to vegetation.

Later, Poselger concluded that illuminating-gas had no influence on plants.

The author experimented with a gas-pipe 3 m. long and 100 mm. in diameter, filled with sandy garden soil. For ten days 2.4 cu. m. illuminating-gas were daily conducted through this earth and consumed in a burner at the end. It was noticeable that the gas lost much of its characteristic odor by passing through the earth. When saturated, the earth was taken out and aerated, a part being transferred to the laboratory to be examined for the characteristic components of illuminating-gas. No ammonia or cyanogen was found.

Some results were obtained in proving the presence of phenol-like bodies, but they were not completely satisfactory.

The proof of heavy carbon sulphides was more satisfactory. 500 g. of earth was left several hours in a flask with 750 cc. of water and occasionally shaken. This was filtered as many times as was necessary to get a clear solution, which had no characteristic peculiarity but an earthy smell. But if one add H_2SO_4 and then a few cc. of bromine-water, this disappears if carbo-sulphides be present. Dr. Pfeiffer puts 100 cc. of the filtrate in an Erlenmeyer matrass, acidifies and allows so much of a dilute bromine solution (10 parts saturated Br solution diluted to 100 parts) to flow out of a burette with glass cock until a yellow color is visible which does not immediately disappear. By a blind test with distilled water it will be found that 0.5 cc. Br water can be detected in the liquid. 100 cc. water after having leached earth which had been impregnated by gas requires 10 per cent. Br water in cu. centimeters.

(*a*) Earth exposed to the air after a gas absorption of several hours, 9 to 10 cc.

(*b*) After nine days kept in a sack, 9.7 to 10.6 cc.

(*c*) Nine days kept in a sack and afterwards dried four days in a thin layer at the temperature of a living-room, 10 to 13.3 cc.

(*d*) 100 days kept in a sack, and after the loss of all moisture of the soil, 11.7 to 12.3 cc.

(*e*) The same after 111 days, 12 cc.

(*f*) The same after 164 days, 11.6 cc. Br water.

From all of this it appears that the strength of the reaction does not diminish after lying half a year. As a practical test he cites the case of breakage of a pipe, in the immediate neighborhood of which a test was taken from a soil unfavorable to absorption. After lying eight days in the laboratory a leaching of 100 cc. of the earth required 5 to 6 cc. Br water.

From the above, one is justified in concluding that a gas-pipe has broken when an investigation of the earth gives the tests for heavy carbo-sulphides, which can be established by the Diazo reaction, but the assumption must be excluded if the reaction cannot be obtained.

If the gas-works would permit specimens of the earth to be examined in places

where leakage is suspected it would more and more diminish the prejudice against illuminating-gas.

33. COLORIMETRISCHE RAUCHDICHTEBESTIMMUNG. P. Fritzche, *Zeitschrift für Analytische Chemie*, vol. xxxvii., p. 92 (1898).

To determine the density of the chimney-smoke a measured volume is drawn into a suitable glass tube furnished with asbestos, and the carbon estimated by heating the tube in oxygen or air and determining the CO_2. This is time-wasting, and besides is only adapted to a laboratory.

A glass tube of about 10 mm. interior diameter and 150 mm. in length is filled with 2 g. of loose cellulose (nitric cellulose). By a short piece of rubber-tubing it is connected with a glass tube equal in diameter, of which the end extends within the interior of the chimney or duct. The other end of the apparatus is connected with an aspirator which draws in 10 to 20 liters of furnace-gas through the cellulose.

At the conclusion of the experiment the apparatus is taken apart. The uppermost black cellulose layer is removed by a pincette to a wide-mouthed stoppered flask of about 300 cc. Together with the partly colored remaining cellulose, both glass tubes are washed out so that the entire soot comes into the cellulose, which is then transferred to the stoppered flask, covered with 200 cc. of water, and well shaken, so that a uniform gray-colored liquid results. In order to judge the amount of soot from the color of the fluid, it is poured into a test-tube 40 to 50 mm. in diameter, with round bottom, and the color compared with a color-scale prepared beforehand.

The scale is prepared by placing 3 g. cellulose in each of a number of tubes containing 5, 10, 15, 20, 25 and 30 mg. soot, to which 200 cc. water has been added and the tubes shaken.

34. ZUR BEURTHEILUNG VON RAUCHSCHÄDEN. H. Ost und C. Wehmer, *Die Chemische Industrie*, vol. xxii., p. 233 (1899).

In 1893–94 the authors undertook an investigation of the cause of certain spots, especially on the leaves of mayflowers and roses, which resembled the effects of acid chimney-gases, but were neither due to these nor to parasites, insects, frost, wind nor dry-rot. They had previously said in print: "On the leaves of various roses, even of those well cared for, often appear violet spots, perhaps due to insect-stings. In the middle of the violet-colored living cells there often appears a sharply defined rust-red spot, the result of death, which resembles an acid-spot to the point of mistaking one for the other. . . . With Dr. Wehmer these spots were examined under the microscope, but no point of difference between the two kinds was discovered.". . . Studies were pursued, principally with roses from gardens and beds northwest of Hanover and practically free from acid-gas. A very common malady is seen in the light or dark violet spots which appear and often cover large areas in the living tissue on the upper side of the leaf, on the edge, and in the middle. The authors observed these spots every year in all collections of roses within and without the city and on the most various kinds, such as Centifolia, La France and Malmaison; they were most strongly marked in spring and autumn, but also found in midsummer when it was wet and cool.

They are probably results of cold and wet weather, as examples from 1896 and 1898 prove. By marks made on leaves in 1898 it was discovered that the violet spots changed again to a duller green. As the respective cells are living, this change of color is not astonishing. More violet is found at the commencement of October-November frosts, long before the leaf exhibits any portions killed by frost; the upper side reddens more and more, and the reddening at last attacks the under side. These violet spots in living tissue are not to be confounded with acid-spots. But the

brown and rust-red spots are deceptively similar to the latter. [Here is introduced a beautifully colored plate illustrating the spots on various rose-leaves.—ED.]

After describing the various spots illustrated in the colored plate the article proceeds: The violet color is probably identical with the often-described but not thoroughly known anthocyanogen.

In dried leaves it is not altered by months of exposure to light, while chlorophyl disappears. Alkalies color it bluish green; acids reddish violet; dilute SO_2 bleaches it slowly; sulphuric acid or extended action of air restores the color, as in the case of the red color of rose-leaves.

Experiments on a number of potted roses in 1898 showed that when treated with SO_2 and afterwards exposed to the sunlight and air, the dead spots, extending through the entire twig, at first discolored, in two or three weeks turned brown or red, and consisted of air-filled collapsed cells with brownish plasma residues. The entire absence of the violet ring in all hitherto examined sulphurous-acid spots is worthy of notice. The dead spots are always surrounded by a narrow blackish zone, in sharp contrast to the green tissue, and this dark boundary proves under the microscope to be free from violet.

Earlier observers have noticed this dark band—viz., Schröder, and Reuss and Hasenclever—but as a characteristic indication of acid- or smoke-injury it has not yet been mentioned, nor more closely investigated.

Nor do the authors wish to generalize too much from the small number of spots they have examined; but they think themselves justified in saying that, at least on rose-leaves, an acid- or smoke-spot is to be recognized by its dark-colored zone. In spots from all other causes, in their examinations, this appearance has been wanting.

Even if one may exclude fungus, insects, wind, frost, and other known causes of spots, in their judgment one is not justified in assuming acid or smoke to be the cause without direct and positive proof.

The article concludes by a description of the gardens and alleys NW. of Hanover, where the observations were made. Although to the south there are large industrial works, cotton-spinning, ultramarine manufactories (the latter of which has been compelled during the last four years to eliminate the acid from the products of combustion, and has the highest chimney, 60 m., or 197 ft.), there is no proof of injury to the vegetation by furnace-gases, although the city's yearly consumption of coal is 450,000 tons.

In the opinion of the authors, the injury due to chimney-gases has been exaggerated. Sometimes in the early morning, and with a southerly wind and heavy atmosphere, the SO_2 from the manufactories is noticeable and unpleasant in the hawthorn alley near the High School, yet the vegetation does not seem to have been injured, although the hawthorn is considered especially sensitive to smoke.

35. SMOKE AND ITS DIMINUTION. B. Donkin, *Engineer*, vol. lxxxvii., pp. 507, 637 (1899).

Increase due to exhaustion of wood and use of coal. Source, factory-boiler and domestic fires. Assuming 5½ million inhabitants of London it is fair to assume that two million domestic chimneys smoke between 7 a.m. and 11 p.m. during winter, and half a million in summer. From 7 to 9 in the morning, when fires are lighted, most smoke is given off. It would be reasonable to assume the amount of smoke given off as equal to that in a chimney 1,000 ft. square.

Restaurants are the greatest offenders, and their number is increasing inordinately.

Nature of smoke. Result of chemical decomposition of coal with insufficient air for complete combustion. Its unburned tarry constituents make up the principal part of smoke. Smoke should be abolished for sanitary reasons.

D. K. Clark, in his *Smoke Abatement* gives ten small pictures of shades of

smoke. Density of smoke has been determined by drawing chimney-gases into previously weighed wool. Prof. Lewicki, of the Saxon Smoke Commission, in 1896, determined the soot in the gases of combustion. Methods are not entirely satisfactory to the author.

In Minay's process the gases are passed through asbestos.

Soot is dried in a current of air and burnt, and the CO_2 determined. The quantity of soot per cu. meter is measured. Ingenious method proposed by Dr. Fritzsch in *Zeitschrift des Vereines deutscher Ingenieure.* The combustion-gases are drawn off and deposited in cellulose, mixed with water and estimated by a color scale. (See *ante.*)

The author introduces a piece of cardboard, 1 ft. square, coated with some adhesive substance, into the bottom of the chimney, and judges the nature of the smoke by the quantity and character of the particles which adhere.

The South Kensington, Manchester, Smoke Abatement Commission used scales of ten shades. The author does not indorse this.

The second English Smoke Commission adopted a scale of only three shades—*i. e.*, "faint," "medium" and "black." Author thinks ten shades too many, and three too few. The best scale (Ringelmann's) is of five shades, and is in use in Switzerland: (1) white transparent vapor; (2) light brown smoke; (3) brownish gray smoke; (4) dense smoke; (5) thick black smoke.

Ringelmann's plan is to represent the different grays into which the shades of smoke are divided by black cross-lines on white paper.

At a certain distance they represent the desired smoke-tints. They are hung up so that the observer can see them and at the same time the smoke from the chimney. These diagrams have been printed in France and the United States.

No. 0. No smoke—All white.

No. 1. Light gray smoke. Black lines 1 mm. thick and white spaces of 9 mm. between.

No. 2. Darker gray smoke. Black lines 2.3 mm. thick and 7.7 mm. apart.

No. 3. Very dark gray smoke. Black lines 3.7 mm. thick and 6.3 mm. apart.

No. 4. Black smoke. Black lines 5.5 mm. thick and 4.5 mm. apart.

No. 5. Very black smoke—All black.

Reischle, chief engineer of the Bavarian Boiler Association, has laid down certain rules for combustion. The HC's must be brought rapidly to a very high temperature before they are allowed to escape; and must be supplied with sufficient air so admitted as to thoroughly mix with the gases (boiler-grates).

On the Continent authorities agree that air should be admitted in two places: in front of the fire, and at the back near the fire-bridge. Mr. Spence, of New Castle, experimented with admitting air above and below the fire-bridge until finally the smoke disappeared.

Headley, in America, admitted the air through hollow passages—brick-work of flues; another plan was through hollow fire-bars.

Careless stoking is the cause of much evil. In boiler-furnaces two methods are good: (1) The American down-draft with two grates. Author thinks this too complicated; does not indorse it. (2) Powdered-coal firing. Author hopeful of this.

Prof. Lewis's four methods of preventing smoke—(See *ante*)—viz., use of anthracite; consumption of products; gaseous fuel; and condensation of tarry components of smoke—all have objections.

English Smoke Commissions.—1881, and Manchester, London, etc., in 1895. Branch Commission, Sheffield, recommend restriction of emission of black smoke from a boiler-chimney to two minutes per hour for one boiler and three minutes for two boilers. All commissions agreed that domestic fires are the most pernicious.

German Smoke Commission.—In Berlin, 1894, a commission was appointed to test various kinds of grates.

Paris Commission.—1894. Observations were made by two persons, each pressing a pen on a moving coated drum graduated by lines to record the different shades of the five-color scale, and also to record time in minutes. The prize was given to the English mechanical stoker. The apparatus which showed the least smoke, did not, however, give the highest efficiency in evaporation.

36. ADDRESS OF PRESIDENT GEORGE BEILBY OF THE SOCIETY OF CHEMICAL INDUSTRY. *Journal of the Society of Chemical Industry*, vol. xviii., p. 643 (1899).

Output of coal in the United Kingdom, 202 million tons. Smoke-nuisance treated from two points of view: (1) scientific investigations of chimney-smoke; (2) various remedies applied. Root of smoke-evil the raw coal burned, and full fruition insured by the method of burning. Total coal consumed during 1898 in the United Kingdom, 157 million tons, of which 76 for power; 81 for heat (46 industrial and 35 domestic). For power, railways, 10 to 12; coasting-steamers, 6 to 8; mines, 10 to 11; factories, 38 to 40. For heat, blast-furnaces, 16 to 18; steel- and iron-works, 10 to 12; other metallurgy, 1 to 2; chemical, pottery, glass, etc., 4 to 6; gas, 13 to 14.

From observations of the exhaust of locomotives, the author thinks steam with the smoke causes rapid deposit of soot. Vegetation along the lines injured, also by steam-boats in narrow rivers, but of course not in coastwise trade. In factories, etc., the classification ought to be (1) hopelessly smoky, and (2) potentially smokeless. The contractors' vertical boiler, the egg-ended boiler of the small city factory, the multitubular boiler for electric-lighting, derived from extinct threshing-machines, are of the first class; the Lancashire boiler of the second. Generation of electricity by steam produces dense black smoke; an anomaly in an apparatus designed to insure purity of light and air. In 1899 the Glasgow and West of Scotland Smoke Abatement Association issued a report on firing Lancashire boilers by hand, and by mechanical stokers. The conclusion was, that means were now known to enable one to work boilers without smoke. In 1898 the Manchester Committee for Testing Smoke-Prevention Apparatus (outcome of suggestion by Chief Inspector under the Alkali Acts, etc.) concluded that a manufacturing district may be freed of smoke (at least from steam-boilers) by carrying out the suggestions in their report.

Remedies: First, mechanical aids to combustion; second, manufacture of smokeless fuels.

Of the first class, mechanical stokers, which may be divided into coking and sprinkling.

In the first, the coal is passed in at the front of the furnace, where the gases are given off and pass over the glowing coals.

Sprinkling stokers distribute the fresh coal over the whole surface of the furnace, but without chilling the fire.

The limits of "throughput" ["Durchsatz"—Ed.] have been widened, so that the throughput may be dropped from 100 to 25 without interfering with economy and smokelessness. Various distributions of air and fuel belong in the class. The author's own experience is that with care and skill smoke can be reduced to an absolute minimum.

Of the second class, destructive distillation in one of two ways—*i. e.*, gas-retort and coke-oven.

(Here follows a description of the details of the working of these various methods, with values of the by-products.)

With a raw-coal value of 1 the various products may vary in value from 1.5 to 3.

Liquid fuel will have a value of 1.5 to 2.5; gas (of 600 B.t.u. per cu. ft.) a value of 2 to 3; coke and briquettes a value of 1 to 1.5.

Coke is not popular as a fuel and is not adaptable to miscellaneous uses for fuel. The remedy is the briquette made with it and tar.

The Partial Combustion of Coal for the Production of Fuel Gas.—There are two producers: the continuous and the intermittent. The continuous gives gas of uniform quality by burning the fuel with a limited supply of air, or air and steam. The intermittent gives a gas rich in combustible components. Air is forced through the mass to heat it and then stopped and steam supplied, producing a rich gas of 350 to 370 B.t.u. First class, 130 to 160 B.t.u.

Remedies for modern methods of heat production.

(Here follows a description with illustrations of the method of introducing gas-heating into private houses.)

37. Recherches sur la formation de l'acide azotique pendant les combustions. M. Berthelot, *Comptes Rendus, Academie des Sciences*, vol. cxxx., p. 1345.

Formation of oxides of nitrogen during combustion of carbon and hydrocarbons had been observed by Cavendish, but not undertaken systematically. In more than a thousand determinations of heat of combustion and formation of organic compounds the author had to determine each time the minute quantity of N_2O_5 formed by the nitrogen contained in the oxygen employed in the experiments.

C, and the binary, ternary, and quaternary compounds formed by the association of H, Cl, and S, with C, were the objects of this study. First C, S, and H.

The N_2O_5 was recovered either in water or in a dilute solution of KHO.

The mean of six experiments in burning amorphous C in an atmosphere of O containing 8 per cent. N was:

Amorphous carbon, . .	HNO_3 0.051 = 0.011 N per 1 g. C burned.
Graphite, ...	HNO_3 0.010
Diamond, ...	HNO_3 0.015
Rough diamond, . . .	HNO_3 0.017

Some ammonia was also determined, ± 0.00046, in amorphous carbon.

Second series, central combustion in an atmosphere of oxygen containing 8 per cent. N at constant atmospheric pressure.

Charcoal was heated to redness and transferred in a small capsule to a vessel containing O.

For 1 g. of burnt charcoal 0.00087 g. HNO_3 = 0.00019 g. N.

In round numbers the weight of the N is about 0.070 of that of the O united with the C; and the weight of O combined with the N is $\frac{1}{5000}$ of that combined with the C.

Combustion of charcoal (amorphous C) in air under normal constant pressure: For one g. of burnt charcoal 0.000096 g. HNO_3 = 0.000021 g. N.

Let us suppose that, in the Department of the Seine, there are burned annually 4 million tons of combustibles of all kinds, coal, oils, etc. (which is the fact, according to the statistics); and assume that the conditions are like those of carbon in the previous experiments. There would result annually 367,000 kg. of HNO_3: say 1,000 kg. per diem. That would make for each hectare of the department 8 kg. derived from human industries. Taking all France, there would result from a similar estimate from human industries 0.1 g. per hectare. This is, however, much too low.

38. The Great Smoke-Cloud of the North of England and Its Influence on Plants. Albert Wilson, *Report of the British Association for the Advancement of Science*, Section K—Botany, p. 930 (1900).

The widespread effect of smoke insufficiently realized. Dwellers in towns often so hardened to it as to be almost oblivious to its presence. The great smoke-producing district of the North of England; its extent; miserable condition of vegetation in some parts of the area. Variation in amount of smoke according to the season Effect in reducing air-transparency; dimness of sky and landscape. Distance to which smoke travels. Smoke often mistaken for haze. Red sunsets in southeast Yorkshire. Atmosphere of the North of England. North of the smoke-area never brilliant with southerly winds. The smoke from Barrow-in-Furness, an isolated town; great distance at which this is noticeable; comparison of its volume with that from the great smoke-area. The characteristic smell from certain large works, and the distance at which it can be detected. Discoloration of rainwater; "black rain." Influence of smoke on sunshine and air-temperature in calm summer weather, and in anti-cyclonic weather during autumn and winter; low day-temperature maxima. Smoke and fog-production. Long-continued smoke-fog of February, 1891. Darkness in and around large cities. Effect of smoke on mosses and hepatics as compared with that on plants of higher order. Smoke at a maximum in winter, when many mosses are in a vegetative condition. Great diminution in their abundance and luxuriousness in the neighborhood of large towns. Peculiar exposure of bark-loving species to smoke-influence, and the cause. Threatened extinction of *Ulota* and *Orthotricha*.

39. MINERAL CONSTITUENTS OF DUST AND SOOT FROM VARIOUS SOURCES. W. N. Hartley, F.R.S., and Hugh Ramage, A.R.C. So. I., *Proceedings Royal Society, London*, vol. lxviii., p. 97 (1901).

Nordenskjöld described two kinds of dust collected by him from Arctic ice: (1) diatomaceæ, and (2) felspathic sand. The third was probably from interplanetary space.

Prof. O'Reilly gave to authors: I. Solid matter which was carried down with hail and collected at Stephen's Green, Dublin; II. Solid matter carried by hail and sleet onto the window-sill of the Royal College of Science, Dublin; III. Pumice from Krakatoa.

I. Contained Fe, Na, Pb, Cu, Ag, Ca, K, Ni, Mn (Ga and Co?).

II. Fe, Ca, Na, Pb, Cu, K, Mn, Ni, Ag, Th (Ga, Ru?).

III. Fe, Cu, Ag, Na, Ni, K, Rb, Mn, Ga, In, Sr.

With the exceptions of Sr, Ni, and Co, the authors found the same constituents in 97 irons, ores and associated minerals. In six meteoric irons they have found the same constituents, with Ni and Co, the latter invariably in smaller quantity than the former.

(Tables of spectroscopic observations are given and explained.)

The authors present two conclusions:

1. The presence of Ni is not certain evidence of extra-terrestrial origin.

2. The dust which fell on calm nights, Nov. 16 and 17, 1897, was very probably cosmic.

The authors call attention to the distribution of Ga. (All minerals, flue-dust, soot, air-dust, iron-ores, bauxite.) They hope to find it concentrated in some mineral as are Th, Cs, Ge and In.

40. SOME OBSERVATIONS ON THE FACTORY AND WORKSHOPS ACT AND THE ALKALI, ETC., WORKS REGULATION BILL OF 1901. Eustace Carey, *Journal of the Society of Chemical Industry*, vol. xxi., p. 214 (1902).

This is principally a discussion of the Acts of Parliament mentioned, with comments upon the intent of the phraseology, and the changes from the old Acts.

41. THE SOOT DEPOSITED ON MANCHESTER SNOW. Wilfrid Irwin, *Journal of the Society of Chemical Industry*, vol. xxi., p. 533 (1902).

After a fall of snow in February, 1902, the author collected a layer 1 inch thick over 100 sq. in. of his garden, 3 miles north of the Town Hall in Manchester. Transferred to a dish, melted, filtered, and extracted solid matter. The dried residue was extracted with benzene, dried, weighed again, and ignited. The following are the results :

100 sq. in. contained 0.073 g. soot; therefore, one acre contained 4.58 kg. = 10.7 lb.; one sq. mile contained 3 tons 1 cwt.

Dr. Knecht, of the Manchester Technical School, took a sample in Whitworth Street (center of the town), and obtained three times as much soot. The difference was due to air-currents.

Almost 300 tons, or 30 tons per day, of soot must have fallen from the Manchester chimneys during the fall of snow.

To ascertain if the soot in the falling snow was a notable part of that observed to fall on the snow a sample of snow was taken underneath the top layer. Tested as before the soot contained:

	Per Cent.
Solid carbon with a little solid matter,	48.6
Grease,	6.9
Ash,	44.5

The percentage of ash was higher than was expected, and much higher than in the soot from chimneys.

The grease, or heavy oil, on heating smelt like burning wood. Though small in amount, it assisted the snow to adhere to the side of the vessel. The author thinks it plays an important part in causing soot to adhere.

Dr. Knecht's soot on analysis gave :

	Per Cent.
Solid carbon with fibrous matter,	45.1
Grease, or heavy oil,	3.5
Ash,	55.4

Prof. E. Knecht collected a layer 0.5 in. thick on a sq. yd. opposite new School of Technology in Whithworth street.

Insoluble residue left after boiling weighed 3.8 g. and contained soot, fibrous matter, and other *débris.*

The filtrate, of brownish color and acid reaction, left a residue of 0.406 g. Residue extracted by hot water and in the aqueous solution, 0.0106 g. Ammonia was obtained chiefly as sulphate. The insoluble part was crystallized $CaSO_4$, a product always present in domestic soot.

Another sample from a garden in Crumpsall contained, besides free acid, ammonium sulphide and chloride. Ordinary chimney-soot contains as much as 15 per cent. ammonium sulphide, which gives it manurial value. The manurial value in the country round is not inconsiderable if enough lime is present, either naturally or artificially added, to neutralize the free sulphuric acid.

42. THE RELATION OF SULPHUR IN LIGHTING-GAS TO AIR-VITIATION. J. S. Haldane, M.D., F.R.S., *Journal of Gas Lighting, Water Supply, etc.*, vol. lxxxiii., p. 564 (1903).

Air in which gas is burned is more oppressive than that to which a proportionate amount of CO_2 has been added. The cause is sulphur. The average English gas contains 0.46 g. per cu. m. Sulphur is present usually nine-tenths as H_2S, and one-tenth in other forms, such as CS_2. The S in gas is largely responsible for the injury to the bindings of books.

(Experiments with gas-combustion product in two rooms.)

The chief conclusions are :

1. The unpleasantness of air in gas-lighted rooms is due to the presence of sulphur in the gas, and varies with the amount of sulphur.

2. Gas purified of CS_2 (by purifier of $CaSO_4$ or other means) is greatly superior hygienically to gas only purified from H_2S.

43. EXAMINATION OF THE ATMOSPHERE OF THE CENTRAL LONDON RAILWAY. Frank Clowes, D.Sc. (1903).

Owing to the absence of combustion in the locomotives, the impurities of the air of the stations were due to the respiration of the passengers and staff. In the tunnel the amount of CO_2 decreased from the Bank end toward Sheppard's Bush terminus.

Dr. F. W. Andrews thus summarizes the results of his bacteriological observations.

1. Micro-organisms present in the air of tunnel as compared with that outside, were as 13 to 10.

2. The number of micro-organisms was great in proportion to the the concentration of human traffic: highest in railway carriages, platforms, and lifts.

3. The air in the railway tunnel does not compare unfavorably with that in inhabited rooms.

4. No pathogenic germs other than those commonly present as saprophytes on the normal body were detected in sufficient quantity to analyze.

5. The number of organisms capable of growing at the temperature of the human body was much greater in the air of the C. L. Ry., but this was due to non-pathogenic *Sarcinæ* and other species.

6. The number of micro-organisms in the air is generally proportional to the degree of chemical contamination—with exceptions.

7. The species in the railway tunnel and in the free air are the same.

The author recommends that no part of the railway air should contain more than twice the amount of CO_2 found in ordinary air; 8 vols. per 10,000 should be the maximum.

44. DIE BESCHÄDIGUNG DER VEGETATION DURCH RAUCH. HANDBUCH ZUR ERKENNUNG UND BEURTEILUNG VON RAUCHSCHÄDEN. Dr. E. Haselhoff, Vorsteher der landwirthschaftlichen Versuchsstation in Marburg, a. d. Lahn, und Dr. G. Lindau, Privat-Docent der Botanik und Kustos aus kgl. botanischer Museum zu Berlin. Bornträger Brothers, Leipsic (1903).

1. *Origin of Smoke.*—Though the visible clouds of smoke may be unpleasant and injurious to vegetation, the real injuries arise from the invisible products of combustion. . . . The amount of SO_2 produced by coal combustion is so little that it will not pay to recover it commercially.

In Lord Derby's Alkali Act, sulphuric acid manufactories were not allowed to discharge more than 5 per cent. of the produced HCl gas. This clause was later altered to forbid more than 0.464 g. of HCl in 1 cu. meter.

A case is known where the waste gases of a sulphuric-acid works in a narrow valley do not reach 4 g. to 1 cu. meter.

Chr. Drelle mentions that in the granting of concessions for new works in Prussia, it is exacted that SO_3 in the waste gases should not exceed 5 g. in a cu. meter.

2. *Signs of Smoke-Injury.*—The rings of growth are difficult to inspect, but the extreme ends of the leaves and stems offer an admirable means for microscopic examination. In forest blights the ends of the needles are discolored. Finally, the needle changes more or less to red. In deciduous leaves, spots on the broader surfaces of the leaves are also more or less red. The spots either appear between the middle rib and the two side ribs, or they surround the leaf. By the manner of formation HCl can be distinguished from H_2SO_4. In young grain or grass the tips become first red, then yellow and finally white.

(A list of plants is here given in the order of their resistance to injury from SO_2 and HCl.)

The wind is the principal factor in spreading the poisonous gases.

D'Arcet suggested a map with concentric circles around the source of contamination. The diameters in the direction of the prevailing winds were made longer than the others. It is not practical.

A better suggestion was made by Reuss. He divides the circle into eight sectors, with the smoke origin in the center. The north sector is between NNW. and NNE.; the NE. sector between NNE. and ENE., etc. South winds traverse the north sector, SW. winds the NE. sector, etc. Each sector for a radius of 1,000 m. contains 39 hectares (ha); between 1,000 and 2,000 m., 118 ha; and for each additional 1,000 m. up to seven, 196, 275, 353, 432, and 511 ha. respectively. Taking the prevalent direction of the wind one can calculate approximately how many tons of SO_2 annually are carried over a given space. The weather, the peculiarities of the ground, and the effect of high stacks must be taken into consideration.

. . . Wislicenus establishes his areas of damages by analysis.

3. In some cases the injury through atmospheric influence resembles smoke-injury. Observation of two or more growth-periods will usually enable one to distinguish the difference, as also in many cases the chemical analysis.

From lack of potash the leaves are discolored to yellowish brown, which becomes white. Lack of P_2O_5 shows itself by the dark green color. Lack of iron from pallor. Some insects living in the interior of the leaves produce yellow or red blotches. The distinction from smoke-poisoning can be discovered by transverse sections under the microscope, when mycelium strings will be observed between the cells. . . . In the controversy between Reuss and Borggreve the latter ascribed the injury of the Kattowitz-Myslowitz district to insects, and not to smoke. The example proves that insects will infest a district already injured by smoke.

4. Freytag says the effect of the destruction of the plants by acid resembles their decay in the autumn.

Sachs observes that in the decay of leaves in the fall first the chlorophyl and starch disappear from the assimilating cells. The solutions of these are conducted through the stem of the leaf to the main stem, where they remain as wood parenchyma, as a reserve, whence they are distributed as needed. During this circulation the leaf cells are filled with a colorless fluid. (Detailed account of the chemical changes, etc.)

5. *Proof of Smoke-Gases in Injury to Vegetation.*—Another way to prove injurious smoke gases is the examination of the air at the place of injury.

Braconnet and Simonin thus investigated the vicinity of Dieuze, near Nancy, in 1848.

Chemical-works producing salt, H_2SO_4, $CaCl_2$, HCl, H_2NO_5, tin salts, lime and sodium carbonate. In the direction of the wind one could detect at a distance of 1.25 miles the odor of SO_2, HCl, and coal-smoke. At distances of 200, 500, and 1,000 m. around the works litmus-papers were suspended, and glass plates moistened with milk of lime. In one or two nights all the test-papers in the path of the wind were reddened if it passed over the works, but not otherwise. The potash-solutions on the glass plates were only partly neutralized, but no chlorine could be detected. The dew shaken from the plants showed a neutral reaction, but a determinable content of Cl, as also of H_2SO_3, Ca, alkalies and organic substances.

The dew of places exposed to wind blowing over the works showed traces of $CaSO_4$ and NaCl, but no $CaCl_2$ or NH_4Cl. . . .

G. Witz (*Comptes Rendus*, vol. c., p. 1385 (1885)), in Rouen, hung up printing-paper charged with lead oxide and noted that it gradually became colorless.

Ost (*Chemische Zeitung*, vol. —, p. 165 (1896)) investigated the gases of the

following works: sulphuric acid, compost-works, ultramarine, chemicals, salt-works, fire-brick-works, and four others. He used, to collect the gases, cotton ("Molleton") which gave 0.07 per cent. ash and was free from H_2SO_4 and F. The material was cut into four parts—three-cornered pieces of about 250 sq. cm. The first were soaked in baryta-water and the last in lime-water. After drying, the bases were sufficiently fixed as carbonates. These cloths were hung up in the trees in the region of the smoke. After 5 to 7 months those soaked in baryta-water were examined for H_2SO_3[1] and those in lime-water for F., whereby 0.054 to 0.190 g. H_2SO_3 and 0.4 to 2.2 mg. F were obtained. Some years later he showed that these substances could be detected even in regions very remote from the source of injury. He took 0.130 to 0.180 g. H_2SO_3 after six months' exposure to represent the normal purity of the atmosphere of a German mountainous forest-region. In the barrens north of Hanover, which are free from all smoke, similar results were obtained. Near the city 0.79 g. was obtained. Similarly Ost carried out Wislicenus's experiments in the Saxon forest-districts by hanging in each district three prepared rags in such a position that the wind should have free access to them. Besides the chemical examination he made tests of the soot by comparisons of their color in clear daylight, made by three or four persons. In this way he distinguished six grades of smudging. Wislicenus thus résuméd his conclusions in 1897:

1. Forest-air, even at great distances from sources of contamination, contains S acids.

2. $BaCO_3$ in 5.5 months was very nearly saturated by the air.

3. The higher degrees of saturation of $BaCO_3$ (which averages 94 per cent.) and of smudging were proportional to the extent of exposure.

4. Although SO_2 penetrates the thicker clumps of firs, it is not so much absorbed on account of lack of light.

5. Soot does not penetrate far into thick clumps of firs.

At first, experiments in rain-water and snow were thought important, but this is only in certain cases. Lately P. Sorauer (*Jahrsbericht für Agricultur Chemie*, Dritte Folge III. der ganzen Reihe 43 er Jahrgang, p. 456 (1900)), proposed to employ plants for absorbing the injurious acids. A year's growth of *Phaseolus vulgaris* in the neighborhood of the suspected works was recommended for this.

All these methods are of doubtful value.

(Here follow tables of acute and of chronic injuries from smoke, in both of which wood-smoke is rated 0. Chronic injury is ascribed "almost exclusively" to SO_2.)

Special Part I. is devoted to the consideration of SO_2 and H_2SO_3

1. The means of condensing the acid-products from the gases of those establishments producing SO_2 may be estimated from the fact that the Freiberg smelting-works paid 55,000 marks for damage in 1864, and only 4,793 in 1870.

. . . In England it is enacted that the amount of S acids discharged into the air must not exceed 4 grains per cu. ft. (9.2 g. per cu. m.) calculated as SO_3. In fact they seldom reach 1.5 grains per cu. ft. The Prussian Minister of Commerce and Manufactures has forbidden that the content of SO_2 in chimney-gases when near inhabited dwellings shall exceed 0.02 per cent. in volume. Angus Smith has calculated that the H_2SO_4 in a million cu. m. of air amounts, in London, to 1,670 g.; in Manchester, to 2,518 g.; in smaller places where H_2SO_4 is manufactured, 2,668 g., and in places where coal is not employed, 474 grams.

Freytag estimates that in the year 1876 in Hanover and Linden 140,000,000 kg. coal was burned and 2,100,000 of kg. SO_2 was discharged into the air. In the narrow

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[1] Sulphurous acid, calculated from sulphuric acid.

valley near Lethemathe on the Lenne, 846,000 kg. of S as SO_2 was discharged into the air in 1879. . . .

2. Besides SO_2, in the above cases, more or less SO_3 is formed, which in presence of steam and water is rapidly changed to H_2SO_4. The water-solution of SO_2 becomes rapidly H_2SO_4. Freytag obtained no SO_2 from rain-water in the vicinity of roasting-furnaces, though traces of this gas were present at the point of oxidation. W. Thörner found no SO_2 in the locomotive-smoke, but only H_2SO_4. . . .

3. SO_2 is never found in the soil. Freytag proved experimentally the rapid conversion of SO_2 to H_2SO_4 by contact with soil. Free H_2SO_4 is not found in soil. The acid reacts on the carbonates. Freytag found in certain places near Aachen in a liter of rain-water 9.0026 to 0.0069 g. HCl, 0.0031 to 0.0194 g. H_2SO_4, of which latter only 0.0038 to 0.0069 g. was free acid. Experiments by Freytag on snow in the neighborhood of the Halsbrücke and Muldner works show the same fact. The sulphates which accumulate in the ground, and especially the $CaSO_4$, are highly favorable to plant-growth, but being soluble, they are carried away by the ground-water.

Schroeder and Reuss proved that, roughly speaking, with the same amount of H_2SO_4 in the soils, the extent of the injury to the plants was measured by the amount of H_2SO_4 in the leaves and needles.

These examples prove that in spite of the strong and repeated influence of the sulphurous- or sulphuric-acid smoke-gases, whether direct or through atmospheric precipitation, no perceptible increase of the content of H_2SO_4 is observed. Hence the conclusion is to be drawn that, exclusive of the reactions of the soil, the S-acid smoke-gases produce no changes in the soil, and therefore there can be no injury to the soil by smoke-gases.

4. (*A*) *Action on the Subterranean Organs.*—From what has been said, it will appear that the action of SO_2 on the roots is excluded because of the rapid oxidation of SO_2 to H_2SO_4. As to the chance of this latter injuring the roots, it is recalled that experiments on snow and rain prove that the quantities of H_2SO_4 which can enter the soil are exceedingly small; of this none would be left uncombined with bases in the ordinary soil, and if one imagine a soil without bases to neutralize it, even then the percolation of the ground-water to lower levels would carry the acid quickly below the roots. In fact, free H_2SO_4 has hardly ever been observed in the soil.

Freytag watered summer wheat, oats and peas growing in beds, morning and evening with 20 liters of water containing, in one case, 4 g. (= 0.02 per cent. SO_2), in another, 5 g. (= 0.025 H_2SO_4), from May 1 to June 15. Then the acid was increased to 5 g. SO_2 and 7 g. H_2SO_4. From July 1 to July 14 a further increase to 8 g. SO_2 and 10 g. H_2SO_4 was made, without the least appearance of disturbance of the ordinary course of growth. On June 15 the oats and peas were gathered, and on July 31 the wheat was harvested. The analyses of the matured products showed no differences unfavorable to the treated plants. Later experiments with the stronger solutions proved that injury only began to be manifest when shortly after the watering a warm wind arose, which evaporated the water and concentrated the acid. As rain can never carry such quantities of acid into contact with the roots it must be conceded that the effect of the smoke-gases on the soil may be neglected.

Reuss fully proved these results by experiments on firs in the forest.

(*B*) *Influence on the Supraterraneous Organs.*—As a result of experiments of J. v. Schroeder and Schmitz-Dumont it follows that injury of plants by SO_2 or H_2SO_4 smoke-gases is always accompanied by an increase of the percentage of H_2SO_4 in the organ of the leaf.

From the foregoing experiments the following conclusions may be drawn:

1. A direct action of SO_2 or H_2SO_4 on the roots of plants in normal farming and forestry conditions is unlikely.

2. An increase in the S-content of the soil through SO_2 and SO_3 gases is without influence on the growth of the plants, and therefore injury to the latter through the action of smoke-gases on the soil may be neglected.

3. An injurious effect on the plant can only occur when SO_2 and SO_3 of the smoke-gases come into actual contact with the leaf-organs of the plant. Concomitant with this injury is an increase in the H_2SO_4 content of the plants. But as the latter may be the result of an increased S-content of the soil only a consideration of the peculiar conditions of each place can properly interpret the phenomenon.

. . . Notwithstanding Stöckhardt convincingly proved that even the smallest amounts of SO_2, by frequent action could work injury to vegetation, Freytag threw doubt upon this (compare last chapter of *Wirkung der Feuchtigkeit und Trockenheit*). This doubt was finally removed by the experiments of J. v. Schroeder and W. Schmitz-Dumont. (*Tharander Förstliches Jahrbuch*, vol. xlvi., p. 1 (1896)). . . . In the determination of the H_2SO_4 in the plant-organs we have an essential means of proving the effect on vegetation of SO_2 and H_2SO_4. . . .

In the case of conifers, and probably other plants, of which the leaf-organs are gummy or waxy, the SO_2 or H_2SO_4 taken up through the rain will not be completely saturated, and thereby the determination of the smoke-injury will be impossible.

(*b*) Morphological Changes.—I. Experimental production of smoke-injuries. II. Exterior changes in the leaf-organs; III. Inner changes in the leaf-organs; IV. Alterations in the stem-organs: acute and chronic injuries.

(*c*) Physiological changes.

(*C*) (P. 130.) Influence of the action of SO_2 by various factors.

(*a*) Light.

(*b*) Influence of moisture and dryness.

(P. 136.) Moist, misty air with a content of 0.003 per cent. by weight, or 0.00135 per cent. by volume, of SO_2, is not injurious. Injury for vegetation has a boundary line between 0.003 and 0.004. . . .

From Freytag and Schroeder's experiments it appears that dryness protects from, and moisture exposes to, injury from smoke-gases. This result agrees with the practical experience that in mist and dew the injury is greater than when the weather is dry.

The influence of SO_2 is greatest when light, moisture and warmth are present.

(*c*) Influence of position.

(*D*) Influence of SO_2 on the cell.

5. Résumé of results of investigation (pp. 143–5, 14 conclusions).

1. Even with strong and repeated treatment of a soil by SO_2 and H_2SO_4 smoke-gases, either directly or through the atmosphere, no essential increase of the sulphur-content of the soil is effected. Disregarding the reactions of the constituent parts of the soil, no change of constitution of the soil takes place, and therefore injury to the soil by SO_2 or H_2SO_4 is out of the question.

2. A direct action of free SO_2 or H_2SO_4 of smoke-gases on the roots of plants is improbable in ordinary farm and forestry conditions. Should an increase of sulphates occur through the action of SO_2 or H_2SO_4 smoke-gases on the soil, it would have no effect on the growth of the plants, and therefore injury of plants through the action of acid smoke-gases on the soil may be excluded from consideration.

3. An injurious effect on plants can only occur when the acid-gases come into direct contact with the leaf-organs of plants. By injury of plants through SO_2 the content of H_2SO_4 in the plant is always increased, but as this occurs when the soil

increases in its content of sulphates, the observation by itself cannot prove injury through acid-gases. The peculiar conditions of each place must be considered.

4. The sensitiveness of plants to SO_2 and H_2SO_4 varies. Even plants of the same kind are differently susceptible, according to their individual position.

5. After long continuous exposure, even so small a quantity as one-millionth of SO_2 has been found injurious to plants. According to Freytag H_2SO_4 is more, while J. v. Schroeder finds it less, injurious to plants than SO_2.

6. The amounts of SO_3 collected from the same amount of leaf-surface of two different plants, under nearly the same circumstances, will of itself afford no measure of the injury done the whole organism of the plants; on the contrary, the specific peculiarities in the organization of the several plants must be taken into account and submitted to proof.

7. The cracks in the leaf-organs have nothing to do with the absorption of SO_2. The gas is not absorbed through these cracks, but by the entire leaf-surface; therefore the different quantities of SO_2 absorbed do not depend upon the number of the cracks but upon the peculiar organization of the individual plants.

8. The effect of the absorption of SO_2 is to disturb the circulation of water, which appears in an increased extrusion of water, and leads to the drying of the leaves.

9. The absorption of SO_2, and consequent disturbance of the water circulation, is for the same quantity of SO_2 greater in a given time with light, higher temperature, and dry air than in darkness, lower temperature, and moist air. The SO_2 and acid gases are in general more injurious by day than by night.

10. Morphologically, the effect of SO_2 is shown by the formation of spots on the leaves, the death of leaves and twigs, the retardation of the rings of growth, and at last the destruction of the plant.

11. In the interior of the cell plasmolysis is induced, the grains of chlorophyl are destroyed, and finally form with the plasma and the other constituent materials a brown amorphous mass. At the same time in most cases, especially if the injury has been gradual, tannin separates out as brown or black rolls in the cells.

12. The manner of action of the SO_2 is to be figured as a disturbance of the life of the plasma in the cell. It probably acts as H_2SO_4, produced in the oxidation of SO_2 by the oxygen of the assimilating chlorophyl-grains in presence of water from the cell-sap.

13. By continuous action of water or rain the SO_3 or H_2SO_4 of the dead leaf-organs, which has been taken out of the air, may be again eliminated. In the conifers, and probably other plants, of which the organs are gummy or waxy, the SO_2 or H_2SO_4 taken from the smoke-gases is not further neutralized in the mass, so that the recognition of smoke-injury is impossible.

14. No absolutely sure botanical means of recognizing the injuries of SO_2 exists, but it is only possible through the complex of outer and inner injuries to conclude their presence. The surest proof is the chemical analysis for H_2SO_4. . . .

6. Instances from actual practice.

(p. 177.) . . . The Freiberg smelting-works were scientifically examined in the middle of the Nineteenth Century, on account of complaints of farmers of the death of plants and cattle. So long as the metallic components of the smoke were held responsible for the damage not much progress was made.

A. Stöckhardt was the first to recognize that SO_2 was the injurious agent. This caused the erection of the H_2SO_4 works, now in operation for 40 years, which utilizes the greater part of SO_2. Yearly the injury diminished, until in the eighties a narrow strip next to the works alone suffered damage and the State purchased it.

The Tharand wood lies in such a position that westerly winds blow the smoke from the Freiberg works' over it.

Inclosing by a line the firs of this wood in which 0.25 per cent. H_2SO_4 has been detected, the area forms a flat ellipse, to the south of which lies the Muldner, and in the middle the Halsbrucker works are situated. To the east toward the Tharand forest the ellipse continues in two gigantic rounded terminations.

The high content of H_2SO_4 near the railways is worthy of remark.

Stöckhardt first showed that the coal-smoke from locomotives contains SO_2, and therefore may produce injury to vegetation. . . .

(P. 304.) Fog. (See report of F. Oliver, *Journal of the London Horticultural Society*, vol. xiii., p. 139 (1891), and vol. xvi., p. 1 (1893)).

Chapter XI. Lighting-gas Very Injurious to Roots. — Experiments by Wehmer in Hanover, and L. Kny (*Botanische Zeitung*, vol. xxix., pp. 852, 867 (1871)), in the botanical garden of Berlin: The supraterranean parts of the plant are seldom damaged. The dead roots are bluish in the interior. As the intensity of the color diminishes towards the periphery Kny concludes the gas is introduced dissolved in water through the root-tips. The phenomenon is not always observable and the conclusion needs further proof.

Chapter XII. Comparison of the Injurious Effects of Acid-Gases.—Tables of minimum and maximum emission of HCl, SO_2, and H_2SO_4 gases of 40 alkali-works by Angus Smith. Also tables of lead-works, smelters, etc.

Turner and Christison think HCl more injurious than SO_2.

Richardson concludes from his experiments that Cl is the most intense in its action, SO_2 next, and HCl least.

Angus Smith, concludes from experiments on water-plants with very dilute, but equally strong, solutions of SO_2, H_2SO_4, and HCl, that H_2SO_4 is the most injurious, HCl next, H_2SO_3 least.

Freytag reaches the same conclusion, and adds that H_2SO_3 is injurious only because it is oxidixed in the moist chlorophyl green leaves to H_2SO_4, which on concentration corrodes. But the results of the experiments of v. Schroeder are opposed to all these views

It cannot be doubted, judging by the action of equal quantities of the beforementioned acids, that H_2SO_3 is the most injurious, and H_2SO_4 and HCl less so. v. Schroeder and Reuss justly point out that the relations are very different when all these gases are simultaneously emitted from a chimney. In such a case HCl and H_2SO_4 condense more quickly, while H_2SO_3 is carried farther. The first does act most strongly on the vegetation in the immediate vicinity, while the H_2SO_3, from its less solubility and consequent slower condensation, has a wider distribution.

H. Ost believes that F gas is much the most injurious of all.

Chapter XIII. Volatile Dust (*Flugstaub*). . . .

4. Effect upon cattle. The dust contains no nourishment and its sharp and pointed particles may cause injury to the intestines of the cattle. Haubner (*Archiv für wissenschaft und praktische Thierheilkunde*, vol. —, pp. 97, 241 (1878)), made many thorough experiments in connection with cows near the Freiberg works.

The cattle feeding on grass reached by the smelting-works gases suffered from a disease. The milch-cows using this fodder gave little milk, and that poor in fat, and after calving the separation of the milk lasted a shorter time. Haubner divided the sickness as follows:

(*a*) So called acid-sickness, a kind of disease of the bones or of the marrow-fluids, caused by the effect of the acids on the fodder-plants.

(*b*) Lung tuberculosis, with its premonitory symptoms, tracheal and bronchial catarrh, cheesy pneumonia.

(*c*) Inflammatory conditions and spasms (*Quetschungen*) of the stomach, and the perforation of the larger intestine (*Labmagen*). The last two are caused by the emitted furnace-dust.

The symptoms of the acid-sickness are: Frequent passages (with acid reaction), pallor and hard skin. The visible mucous and conjunctiva become noticeably pale, the skin becomes dry, hard, and immobile, especially in the region of the barrel (*Rippengewölbe*), is dusty and uncleanly; the hair is lusterless, rough and tangled; besides this comes later a diminution of the appetite, and of the milk, and gradual attenuation. The urine is remarkably pale, clear, like water, without deposit, and with acid reaction. The animals stand with lowered head and neck, cannot sufficiently raise them. The back is bent and the belly lowered. The hind-quarters take a straight, stiff position in all joints, which in the hock (*Fesselgelenk*) is first manifested by a stiff position of the pastern. Then follow the hip (*Sprung*) and hind knee-joints, so that the angles continually diminish. Later symptoms appear which indicate disease of the bones, as occasional pains in the joints, indicated by stiffness and difficulty in moving, etc.

These appearances are seen more clearly in young than in old cattle. Freytag thinks these conclusions go too far and Haselhoff agrees with him.

General remarks on smoke-expertism are summarized as follows:

Chapter I. R. Hartig thinks the measure of injury to vegetation by the determination of H_2SO_4 has merely an historic interest.

Borggreve (*Waldschäden im oberschlesischen Industriebezirk*, Frankfort (1895)), says "by these eternal commonplace H_2SO_4 determinations" no more is proven than we have long known. J. v. Schroeder has justly and sharply retorted to this sneer. He says: "If in any future judicial process I should have Borggreve's objections opposed to any conclusions I should draw from sulphuric-acid determinations, I should simply say that Borggreve says of himself, in several parts of his book, that he is not enough of a chemist to judge of chemical methods and understands little or nothing of chemistry."

Chapter II. Botanical Examination.

Chapter III. Examination of the locality, and Selection of specimens.

For forest- and fruit-plants, the middle of July is the best time (in Germany). For field-plants, the middle of June.

It is useful to take specimens from the greatest number of directions.

Wislicenus suggests the observation of the top of the chimney to ascertain which is the prevailing direction of the wind by the greater deposit of soot on the side of the chimney most protected from the wind.

Chapter IV. Chemical Examination.

In preparing the specimen for analysis it must be carefully cleaned of sand-particles and brushed with a fine brush or rinsed with water. Plants holding much water must be dried at 50° or 60°. After a thorough mixing, the whole sample should be comminuted as finely as possible in an Excelsior mill, or if that is not enough, in a mortar.

Chapter V. Botanical Examination.

Chapter VI. Estimation and Prevention of Injury.

Weslicenus's formula for injury is $S = \sqrt[3]{\frac{c.kw.}{d^3}} \times \frac{C}{X}$

S = proportion of injury; c = acid-content of the smoke-gases in volume.

k = yearly consumption of coal; w = particular percentage of direction of the wind; d = minimum distance; C = constant of the injurious kind of gas.

X = factor for the reduction of the distance by the influence of acid-fogs, etc.

Hasselhoff gives the formula without knowing anything of its reliability.

By the prevention of smoke an industrial works can only be the gainer, and generally by the prevention of the escape of acid gases.

It is not practicable to establish a permissible percentage of injurious products which may be emitted for all parts of a country. In Germany each separate case is judged by itself. As in Germany the prevailing winds are west and south, concessions for industrial establishments to the west and south of forest or cultivated lands should only be granted at considerable distances. In hilly regions the direction of the wind is to be more carefully considered than in flat.

45. SMOKE AND ITS ABATEMENT. Prof. C. H. Benjamin, *Transactions of the American Society of Mechanical Engineers*, vol. xxvi., p. 713 (1904–05).

Bituminous coal must be used, and no legislation can prevent it. Other fuels are in limited supply. Abatement is possible; prevention of its injuries is not. (*a*) Smoke is a nuisance, (*b*) can be easily abated, and (*c*) this abatement may be made the source of profit.

Black smoke is due to hydrocarbons in the fuel not having been provided with sufficient oxygen to consume them. The hydrogen is burned, and the carbon is carried off as soot. When supplied with enough oxygen, it burns with a yellow flame; when with too little, a reddish flame; soot is then formed. The conditions of perfect combustion are sufficient air, sustained high temperature, and thorough firing of the gas. Trees and shrubs are killed by the sulphurous content of smoke. With hand-firing great irregularities are experienced. Steam-jets are employed: they should be semi-automatic. The best solution of the smoke problem is mechanical handling of coal.

Mechanical stokers may be divided into: inclined; shaking grates; traveling, or chain grates; and underfeed stokers.

Inclined.—Wilkinson, Brightman, and Roney stokers, single incline; Murphy and Detroit stokers, double incline. Disadvantages: Both forms need frequent cleaning, and with clinker-making coal too much slicing.

Traveling, or Chain-Grate.—Babcock, Wilcox and Green.

Benjamin thinks this is the best form of grate used.

Underfeed Stokers.—The American and the Jones. Economical and practically smokeless.

A smoky chimney is an indication of waste, but a smokeless chimney is not necessarily an indication of economy.

Letters from persons using mechanical stokers favor this system.

(Table of efficiency of combustion.)

A recent improvement that promises well is a combination of steam-jets and oil-vapor at the bridge-wall. Baffle-walls have also assisted in maintaining high temperature and mixing the gases.

(Rules for firing in a locomotive by a railroad.)

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Velocity of Galena and Quartz Falling in Water.

BY ROBERT H. RICHARDS, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, BOSTON, MASS.

(New York Meeting, April, 1907.)

I. Introduction.

The object of this paper is to enlarge the field of settling velocities treated by me in my former papers, Close Sizing Before Jigging, and Sorting Before Sizing.[1] There seemed need of work both on coarser and on finer sizes.

Messrs. A. Sidney Warren and M. L. Nagel undertook the investigation for the coarser sizes, from 12.85 mm. down to 2.05 mm. diameter. Their work, because of the closer spacing and because of the increased number of observations and consequent stronger averages, called for a revision of the former work.

Messrs. G. A. Barnaby and Ralph Hayden undertook this part of the work, from 2.49 mm. down to 0.28 mm., which is near the limit of sifting. Their work covers the ground much more minutely and comprehensively than the former papers.

There remained to be covered the portion of the field too fine for investigation with the sieves. This part, covering the range of grains from 0.48 to 0.03 mm., was undertaken by Mr. E. S. Bardwell. For it he used the elutriation method.

II. The First, or Coarsest, Section of the Field.

The first desideratum in this investigation was a series of sieves for sizing the sands preparatory to making the tests. It became necessary, therefore, to decide on a sieve-scale for this purpose.

A sieve-scale is a series of sieves in which the dimensions of the holes of the successive members form a series increasing by a definite ratio. There are three natural sieve-scales: 1, progressing by doubling the width of the hole for each suc-

[1] *Trans.*, xxiv., 409 to 486 (1894), and xxvii., 76 to 106 (1897).

cessive member of the series; 2, progressing by doubling the area of the hole for each successive member of the series, for which the multiplier is $\sqrt{2}$, or 1.41421; 3, progressing by doubling the volume of the grain for each successive member of the series. The multiplier for this is $\sqrt[3]{2}$, or 1.25993. The second scale is the one adopted by Rittinger. In the present work it was thought wise to diminish the intervals more than would ever be required by mill-work in order to meet the most exact demands for the settling-values of grains.

The sieve-scale chosen was obtained from the Rittinger scale by interpolating another sieve between each member of his series, and is called in the paper double Rittinger. The multiplier which produces this result is $\sqrt[4]{2}$, or 1.18921. (See Table I.)

TABLE I.—*The Three Natural Sieve-Scales and Double Rittinger.*

Double Width.	Double Area. Rittinger.	Double Volume.	Double Rittinger.
1.	1.	1.	1.
			1.18921
		1.25993	
	1.41421		1.41422
		1.58742	
			1.68180
2.	2.	2.	2.
			2.37842
		2.51986	
	2.82842		2.82844
		3.17484	
			3.36360
4.	4.	4.	4.
			4.75684
		5.03972	
	5.65684		5.65688
		6.34969	
			6.72721
8.	8.	8.	8.
			9.51368
		10.07944	
	11.31368		11.31376
		12.69938	
			13.45443
16.	16.	16.	16.

In order to produce this double Rittinger sieve-scale, the values given in Tyler's catalogue of screens were studied and

the sieves that were nearest to double Rittinger values were taken. Table II. gives, in the first column, double Rittinger figures; in the second column, the nearest values from Tyler's catalogue. The third and fourth columns are Warren's and Nagel's actual measurements of the holes in the Tyler screens. The fifth column is the average of Nagel's and Warren's figures, which is adopted as defining the sizes of grains used in the tests. The sixth is the average of each screen size with the one above it, and therefore gives approximately the average of the diameters of the grains which would pass through the coarser screen and rest on the finer one in each case.

TABLE II.—*Double Rittinger Sieve-Scale Used by Warren and Nagel.*

Double Rittinger.	Tyler's Catalogue.	Nagel's Measurement.	Warren's Measurement.	Average of Nagel and Warren.	Average of Screen with One Above.
Width of Holes in Millimeters.					
13.454	....	12.80	12.90	12.850	....
11.314	11.210	11.01	11.01	11.010	11.930
9.514	9.696	9.49	9.52	9.505	10.257
8.000	8.047	7.80	7.78	7.790	8 647
6.727	6.751	6.83	6.86	6.845	7.317
5.657	5.786	6.00	5.94	5.970	6.407
4.757	4.690	4.94	4.95	4.945	5.457
4.000	3.923	4.21	4.21	4.210	4.577
3.363	3.299	4.15	4.10	4.125	4.167
2.828	2.818	2.84	2.81	2.825	3.475
2.378	2.360	2.83	2.81	2.820	2.823
2.000	1.980	2.07	2.04	2.055	2.437

In measuring the sieves Warren and Nagel found that the spaces were by no means all of exactly equal size, and were often rectangles instead of squares. First the diameters of the wires were measured with calipers. Six measures each by Warren and Nagel were obtained and the mean of the 12 measures was adopted. Next, a certain number of meshes was counted off on each screen and the distance across those meshes was measured in millimeters and tenths. From this measurement was subtracted the diameter of the screen-wire multiplied by the number of meshes, and this remainder was divided by the number of meshes. From six such measurements on each screen by each observer, an average was obtained giving the figures in columns three and four.

Galena and quartz were selected for this investigation, partly because they are among the commonest minerals in the dressing-works, and also because very pure samples of each were available.

The galena used for this work was from the jigs of Joplin, Mo., and it was crushed by rolls to pass a screen with holes 13.450 mm. diameter. Determinations of its specific gravity were 7.49, 7.50, 7.56, 7.46; average, 7.50.

The quartz used for this work was plain white quartz purchased in the market. Its locality was not known. It was crushed to pass the above screen, and its specific gravity was tried four times, each giving 2.65 as the specific gravity.

The samples were next sized by screening them on the series of sieves, beginning with the coarsest and ending with the finest. Each size included grains which passed through the next coarser screen and failed to go through the next finer.

Experiments in testing the velocity of falling grains were made in a vertical tube, 11.5 ft. high and 8 in. in diameter, filled with water. This tube, Fig. 1, consisted of three sections: the upper one a flanged glass tube, *R*, 2 ft. high; the middle one a galvanized iron tube, *S*, flanged at each end, 7.5 ft. high; and the lower one a flanged glass jar, *T*, 2 ft. high.

The joint between the upper glass tube and the galvanized iron tube consisted of the glass flange, *C*, and the iron flange, *E*, an iron ring, *A*, a felt washer, *B*, a rubber gasket, *D*, and four bolts, *F*.

The joint between the lower end of the galvanized iron pipe and the flanged glass jar consisted of two flanges, *I* and *J*, the rubber gasket, *L*, a felt cushion, *G*, and a wooden plate, *H*, with four bolts, *K*, that extend the length of the jar.

The longest even distance that could be laid off conveniently for a measured course was 2800 mm.; 18 in. from the top of the tube two pasters, *N*, were put on the glass at front and back, so that the top edges give the upper sight and form a range for the starting-point. The space at the top was left to allow the grain to acquire full velocity; 2800 mm. below these pasters, two other pasters, *P*, were put on the lower jar to mark the finish. The top edges of these formed the lower sight. The top of the tube had a loosely-fitted zinc cover with a hole about 0.5 in. in diameter in the exact center. Through

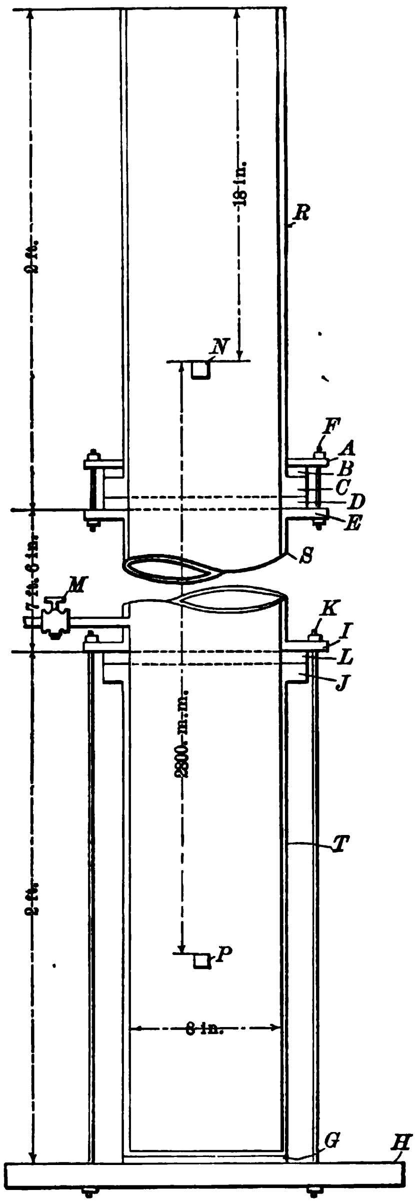


Fig. 1.—Sorting-Tube for the Coarser Group.

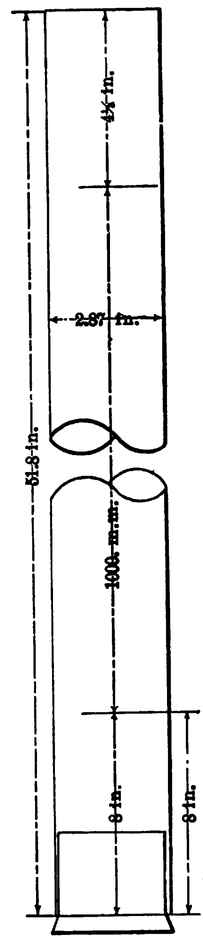


Fig. 2.—Sorting-Tube for the Middle Group.

this hole the grains were dropped into the tube, after having been wet thoroughly, to exclude all air bubbles.

TABLE III.—*Warren and Nagel's Seconds of Time for Galena Grains to Drop through* 2800 *mm.*

Through 12.85 mm. On 11.01 mm. Aver. Diam., 11.98 mm.

Secs.	†No. of Grs.
2.0	1
2.2	5
2.4	29
2.6	23
2.8	21
3.0	15
3.2	3
3.4	2
3.6	0
3.8	0
4.0	1
*2.67	‡100

Through 11.01 mm. On 9.50 mm. Aver. Diam., 10.257 mm.

Secs.	No. of Grs.
2.0	0
2.2	0
2.4	4
2.6	23
2.8	28
3.0	25
3.2	9
3.4	5
3.6	3
3.8	1
4.0	2
2.91	100

Through 9.50 mm. On 7.79 mm. Aver. Diam., 8.64 mm.

Secs.	No. of Grs.
2.0	0
2.2	0
2.4	0
2.6	2
2.8	16
3.0	30
3.2	28
3.4	14
3.6	8
3.8	2
4.0	0
3.14	100

Through 7.79 mm. On 6.84 mm. Aver. Diam., 7.31 mm.

Secs.	No. of Grs.
2.6	0
2.8	1
3.0	10
3.2	23
3.4	21
3.6	20
3.8	13
4.0	4
4.2	5
4.4	1
4.6	0
4.8	2
3.51	100

Through 6.84 mm. On 5.97 mm. Aver. Diam., 6.40 mm.

Secs.	No. of Grs.
3.0	1
3.2	6
3.4	19
3.6	18
3.8	23
4.0	7
4.2	7
4.4	7
4.6	3
4.8	2
5.0	0
5.2	2
3.80	100

Through 5.97 mm. On 4.94 mm. Aver. Diam., 5.45 mm.

Secs.	No. of Grs.
3.2	1
3.4	4
3.6	9
3.8	14
4.0	33
4.2	17
4.4	6
4.6	5
4.8	6
5.0	1
5.2	3
5.4	1
4.10	100

Through 4.94 mm. On 4.21 mm. Aver. Diam., 4.57 mm.

Secs.	No. of Grs.
3.6	1
3.8	5
4.0	15
4.2	11
4.4	18
4.6	14
4.8	8
5.0	6
5.2	4
5.4	6
5.6	3
5.8	1
6.0	2
6.2	0
6.4	2
6.6	1
6.8	0
7.0	2
7.2	1
4.69	100

Through 4.21 mm. On 4.12 mm. Aver. Diam , 4.17 mm.

Secs.	No. of Grs.
3.8	2
4.0	4
4.2	10
4.4	10
4.6	14
4.8	19
5.0	15
5.2	7
5.4	3
5.6	6
5.8	2
6.0	3
6.2	2
6.4	1
6.6	1
6.8	1
7.0	0
4.88	100

Through 4.12 mm. On 2.825 mm. Aver. Diam., 8.47 mm.

Secs.	No. of Grs.
4.0	4
4.2	2
4.4	6
4.6	7
4.8	16
5.0	27
5.2	12
5.4	3
5.6	5
5.8	6
6.0	2
6.2	3
6.4	3
6.6	1
6.8	2
7.0	1
5.13	100

Through 2.825 mm. On 2.820 mm. Aver. Diam., 2.828 mm.

Secs.	No. of Grs.
5.0	2
5.2	8
5.4	18
5.6	14
5.8	11
6.0	14
6.2	12
6.4	8
6.6	3
6.8	3
7.0	4
7.2	1
7.4	1
7.6	0
7.8	1
8.0	0
5.91	100

Through 2.820 mm. On 2.055 mm. Aver. Diam., 2.487 mm.

Secs.	No. of Grs.
4.8	1
5.0	0
5.2	1
5.4	5
5.6	8
5.8	11
6.0	18
6.2	14
6.4	9
6.6	6
6.8	5
7.0	8
7.2	4
7.4	4
7.6	2
7.8	1
8.0	1
8.2	0
8.4	2
6.34	100

* Average. † Number of grains. ‡ Total number of grains.

The 100 grains for the test were taken wholly at random by spreading the group out on a glass plate in a long narrow row from which alternate inches were taken and the others rejected. This was repeated until the quantity was nearly reduced to 100 grains. This was again spread out in a long narrow row and the grains were taken from the end for the test until the row was almost used up. Grains in the galena set which evidently included blende or quartz were not accepted.

The timing was done with great care by two observers, one at the upper sight, the other at the lower sight. The upper observer dropped a grain through the hole in the zinc top, and when the grain passed the sight called to the man below, who started his stop-watch. The latter stopped his watch when the grain passed the lower sight. The figures recorded in Tables III. and IV. represent the time elapsed.

Tables III. and IV. show the number of galena and quartz grains that fell 2800 mm. at each fifth of a second between the fastest and the slowest speed for each size. The average velocity given at the foot of each column is that for the whole 100 grains. The final summing up of these values is given in Table XI.

A series of tests was made to see if the groups taken at random really covered the field. For this purpose very flat, slow moving grains were selected. Occasionally a flat grain was found that fell more slowly than any in the table, but the number was too small to affect the results.

A test was made to ascertain the error in timing. We will use the word "lag" to represent the time elapsed between the passing of the particle and the record on the stop-watch. The lag of seeing and recording on the stop-watch by the same observer we will call single lag, the acts of a single brain. The lag of seeing and reporting by one observer to the other who hears and records on the stop-watch we will call "double lag," the acts of two brains. When the upper observer recorded both events on the watch he made single lag at the start and double lag at the finish. The time was, therefore, too long by a single lag. When the lower observer held the watch, he made double lag at the top and single lag at the bottom. This time was too short by a single lag. The average difference on 42 tests showed that the time was 0.67 second (double lag) longer when

TABLE IV.—*Warren and Nagel's Seconds of Time*

Through 12.85 mm. On 11.01 mm. Aver. Diam., 11.93 mm.		Through 11.01 mm. On 9.50 mm. Aver. Diam., 10.257 mm.		Through 9.50 mm. On 7.79 mm. Aver. Diam., 8.64 mm.		Through 7.79 mm. On 6.84 mm. Aver. Diam., 7.31 mm.		Through 6.84 mm. On 5.97 mm. Aver. Diam., 6.40 mm.		Through 5.97 mm. On 4.94 mm. Aver. Diam., 5.45 mm.	
Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.
5.4	2	5.4	1	5.4	1	5.4	1	6.4	1	7.4	1
5.6	2	5.6	1	5.6	1	5.6	0	6.6	0	7.6	0
5.8	6	5.8	3	5.8	1	5.8	0	6.8	0	7.8	0
6.0	12	6.0	2	6.0	0	6.0	0	7.0	1	8.0	8
6.2	13	6.2	2	6.2	1	6.2	0	7.2	0	8.2	3
6.4	12	6.4	8	6.4	2	6.4	0	7.4	2	8.4	1
6.6	6	6.6	8	6.6	8	6.6	0	7.6	1	8.6	1
6.8	7	6.8	6	6.8	11	6.8	2	7.8	4	8.8	5
7.0	16	7.0	15	7.0	10	7.0	1	8.0	6	9.0	8
7.2	2	7.2	3	7.2	6	7.2	1	8.2	8	9.2	3
7.4	3	7.4	11	7.4	7	7.4	5	8.4	8	9.4	7
7.6	5	7.6	6	7.6	5	7.6	10	8.6	6	9.6	3
7.8	5	7.8	4	7.8	5	7.8	5	8.8	5	9.8	9
8.0	2	8.0	13	8.0	11	8.0	9	9.0	7	10.0	7
8.2	3	8.2	2	8.2	6	8.2	8	9.2	4	10.2	9
8.4	0	8.4	3	8.4	5	8.4	8	9.4	9	10.4	3
8.6	0	8.6	1	8.6	5	8.6	1	9.6	4	10.6	1
8.8	0	8.8	3	8.8	4	8.8	13	9.8	8	10.8	1
9.0	1	9.0	2	9.0	8	9.0	3	10.0	8	11.0	4
9.2	0	9.2	2	9.2	1	9.2	1	10.2	2	11.2	4
9.4	0	9.4	2	9.4	2	9.4	2	10.4	2	11.4	5
9.6	2	9.6	0	9.6	1	9.6	8	10.6	4	11.6	1
9.8	0	9.8	0	9.8	1	9.8	5	10.8	2	11.8	4
10.0	1	10.0	0	10.0	1	10.0	5	11.0	4	12.0	0
6.77	100	10.2	0	10.2	1	10.2	1	11.2	5	12.2	1
		10.4	0	10.4	2	10.4	2	11.4	4	12.4	5
		10.6	1	10.6	1	10.6	0	11.6	0	12.6	0
		10.8	1	10.8	1	10.8	2	11.8	1	12.8	0
		11.0	0	11.0	1	11.0	1	12.0	3	13.0	3
		7.43	100	11.2	0	11.2	5	12.6	0	13.2	2
				11.4	0	11.4	1	13.0	0	13.4	0
				11.6	0	11.6	2	14.0	0	13.6	1
				11.8	1	11.8	2	14.2	0	13.8	1
				12.0	0	12.0	1	14.8	1	14.0	0
				7.89	100	8.93	100	9.46	100	14.2	1
										14.4	0
										14.6	1
										14.8	0
										15.0	0
										15.2	1
										15.4	0
										15.6	0
										16.0	1
										10.45	100

the watch was at the top than when it was at the bottom. When, therefore, the watch was held at the bottom, as was the case in the tests, the time of settling recorded on the watch was 0.33 second (one-half of 0.67 second) too short. The figures given in Tables III. and IV. show the actual record. In Table XI. the error has been corrected.

A separate test was made to record, together with the velocities, the shapes of the grains. A group of galena grains and a group of quartz grains passing through the screen 4.125 mm.

for Quartz Grains to Drop through 2800 *mm.*

Through 4.94 mm. On 4.21 mm. Aver. Diam., 4.57 mm.		Through 4.21 mm. On 4.12 mm. Aver. Diam., 4.17 mm.		Through 4.12 mm. On 2.825 mm. Aver. Diam., 3.47 mm.		Through 2.825 mm. On 2.820 mm. Aver. Diam., 2.823 mm.		Through 2.820 mm. On 2.055 mm. Aver. Diam., 2.437 mm.	
Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.
7.8	1	7.8	1	8.8	1	10.6	1	10.8	1
8.0	0	8.0	0	9.0	0	10.8	0	11.6	1
8.2	0	8.2	0	9.2	2	11.0	0	11.8	1
8.4	1	8.4	0	9.4	0	11.4	1	12.0	1
8.6	1	8.6	0	9.6	1	11.8	2	12.4	2
8.8	1	8.8	0	9.8	1	12.0	4	12.8	0
9.0	6	9.0	3	10.0	2	12.2	2	13.0	4
9.2	2	9.2	2	10.2	3	12.4	4	13.2	2
9.4	1	9.4	0	10.4	2	12.6	3	13.4	1
9.6	3	9.6	3	10.6	1	12.8	2	13.6	1
9.8	4	9.8	3	10.8	4	13.0	5	13.8	1
10.0	11	10.0	5	11.0	2	13.2	4	14.0	5
10.2	7	10.2	6	11.2	2	13.4	3	14.2	3
10.4	2	10.4	5	11.4	3	13.6	0	14.4	3
10.6	6	10.6	4	11.6	1	13.8	6	14.6	4
10.8	6	10.8	5	11.8	6	14.0	2	14.8	3
11.0	7	11.0	6	12.0	7	14.2	4	15.0	7
11.2	2	11.2	1	12.2	0	14.4	5	15.2	1
11.4	4	11.4	1	12.4	6	14.6	3	15.4	1
11.6	1	11.6	3	12.6	1	14.8	5	15.6	5
11.8	5	11.8	4	12.8	8	15.0	4	15.8	3
12.0	2	12.0	9	13.0	8	15.2	2	16.0	5
12.2	0	12.2	0	13.2	0	15.4	2	16.2	7
12.4	1	12.4	2	13.4	3	15.6	2	16.4	2
12.6	1	12.6	0	13.6	4	15.8	1	16.6	1
12.8	3	12.8	3	13.8	2	16.0	2	16.8	2
13.0	5	13.0	5	14.0	1	16.2	0	17.0	0
13.2	1	13.2	2	14.2	1	16.4	1	17.2	1
13.4	3	13.4	2	14.4	2	16.6	3	17.4	1
13.6	1	13.6	0	14.6	3	16.8	1	17.8	2
13.8	3	13.8	3	14.8	2	17.2	1	18.0	1
14.0	0	14.0	3	15.0	2	17.4	1	18.2	2
14.2	0	14.2	0	15.2	1	17.8	0	18.4	3
14.4	0	14.4	1	15.4	1	18.0	2	18.6	1
14.6	1	14.6	3	15.6	1	18.4	4	19.0	1
14.8	0	14.8	3	15.8	4	18.6	1	19.2	2
15.0	0	15.0	4	16.0	2	18.8	2	19.4	2
15.2	1	15.2	0	16.2	2	19.0	2	19.6	2
15.4	0	15.4	0	16.4	1	19.2	1	19.8	2
15.6	1	15.6	1	16.6	1	19.4	1	20.0	1
15.8	1	15.8	1	16.8	0	19.6	2	20.2	1
16.0	1	16.0	1	17.0	3	19.8	2	20.4	1
16.2	1	16.4	1	17.2	0	20.0	2	20.6	1
17.0	1	16.6	1	17.4	2	20.2	1	20.8	1
17.4	1	16.8	2	17.6	0	20.8	1	21.0	1
18.0	1	17.0	0	17.8	1	21.0	1	21.2	1
11.36	100	17.8	1	18.0	0	21.4	1	21.4	1
		18.0	0	13.03	100	21.8	1	21.6	1
		12.08	100			15.31	100	22.0	2
								22.8	1
								23.2	1
								16.37	100

and resting on the screen 2.825 mm. were taken for this purpose. (Tables V. and VI.) It will be noted that the slower grains are nearly all long or flat and that the faster grains are nearly all cubical. The slightly slower speed of the grains in this test as compared with those of the former test (Tables III.

TABLE V.—*Galena of 3.47 mm. Average Diameter Dropped 2800 mm.*

Timer.	Seconds.	Weight.	Description.	Timer.	Seconds.	Weight.	Description.
N.	4.0	0.38	Massive.	W.	5.2	0.16	Irregular.
N.	4.0	0.37	Massive, irregular.	W.	5.2	0.14	Cubical.
W.	4.2	0.55	Cubical.	N.	5.4	0.50	Irregular, flat.
N.	4.2	0.46	Cubical.	W.	5.4	0.28	Irregular.
N.	4.2	0.40	Massive.	N.	5.4	0.26	Cubical.
W.	4.2	0.26	Massive.	W.	5.4	0.25	Square, long.
N.	4.4	0.49	Cubical.	W.	5.4	0.22	Irregular.
N.	4.4	0.45	Long, irregular.	W.	5.4	0.21	Cubical.
N.	4.4	0.40	Cubical.	N.	5.4	0.19	Massive.
N.	4.4	0.33	Massive.	N.	5.4	0.19	Long.
W.	4.4	0.31	Cubical	N.	5.4	0.16	Massive.
N.	4.4	0.29	Cubical.	N.	5.4	0.18	Massive.
N.	4.4	0.28	Massive.	N.	5.4	0.15	Cubical.
N.	4.4	0.27	Long, irregular.	W.	5.6	0.45	Long, flat.
N.	4.4	0.27	Cubical.	N.	5.6	0.36	Long, irregular.
N.	4.4	0.26	Cubical.	W.	5.6	0.28	Massive, flat.
N.	4.4	0.20	Cubical.	N.	5.6	0.26	Long, irregular.
N.	4.4	0.17	Cubical.	W.	5.6	0.18	Massive.
N.	4.6	0.44	Cubical.	N.	5.8	0.62	Square, long.
N.	4.6	0.39	Massive.	W.	5.8	0.43	Long.
N.	4.6	0.38	Massive.	W.	5.8	0.26	Massive, irregular.
W.	4.6	0.38	Irregular.	N.	5.8	0.19	Long, flat.
N.	4.6	0.33	Massive.	W.	5.8	0.17	Massive, irregular.
N.	4.6	0.33	Long, massive.	W.	5.8	0.16	Cubical.
N.	4.6	0.33	Square, flat.	W.	5.8	0.13	Massive.
W.	4.6	0.18	Cubical.	W.	5.8	0.12	Cubical.
W.	4.6	0.15	Ordinary.	W.	6.0	0.43	Long, massive.
N.	4.8	0.67	Long, flat.	W.	6.0	0.26	Cubical.
N.	4.8	0.42	Irregular.	W.	6.0	0.21	Irregular.
W.	4.8	0.38	Massive.	N.	6.0	0.21	Cubical.
N.	4.8	0.33	Irregular.	W.	6.0	0.15	Irregular.
N.	5.0	0.36	Irregular.	N.	6.2	0.30	Long, irregular.
W.	5.0	0.35	Massive.	W.	6.2	0.26	Square, flat.
W.	5.0	0.30	Cubical.	N.	6.2	0.22	Irregular, massive.
N.	5.0	0.28	Massive.	W.	6.2	0.14	Cubical.
N.	5.0	0.27	Irregular.	W.	6.2	0.14	Cubical.
N.	5.0	0.18	Cubical.	W.	6.2	0.12	Square, flat.
N.	5.0	0.21	Cubical.	W.	6.4	0.31	Long, irregular.
N.	5.0	0.18	Cubical.	W.	6.4	0.30	Long, massive.
W.	5.0	0.18	Cubical.	N.	6.4	0.10	Irregular.
W.	5.2	0.63	Long, irregular.	W.	6.6	0.23	Massive, flat.
W.	5.2	0.48	Square, long.	W.	7.0	0.21	Flat.
N.	5.2	0.34	Long, massive.	W.	7.0	0.18	Square, flat.
N.	5.2	0.30	Long, flat.	N.	7.0	0.17	Wide, flat.
W.	5.2	0.30	Irregular.	W.	7.0	0.15	Flat, irregular.
W.	5.2	0.28	Cubical.	W.	7.2	0.20	Long, flat.
W.	5.2	0.27	Cubical.	N.	7.4	0.22	Long, flat.
N.	5.2	0.27	Irregular.	W.	7.4	0.19	Square, flat.
W.	5.2	0.26	Cubical.	W.	7.4	0.17	Wide, flat.
N.	5.2	0.24	Massive.	N.	7.4	0.15	Flat.
				N.	7.8	0.09	Irregular, flat.
				W.	8.0	0.10	Cubical.
				N.	8.0	0.26	Flat.
				N.	8.6	0.15	Irregular, flat.
				W.	9.0	0.16	Wide, flat.
					5.51	0.27	Average.

TABLE VI.—*Quartz of 3.47 mm. Average Diameter Dropped 2800 mm.*

Timer.	Seconds.	Weight.	Description.	Timer.	Seconds.	Weight.	Description.
N.	8.8	0.07	Ordinary.	W.	13.0	0.08	Irregular.
W.	9.2	0.08	Ordinary.	W.	13.0	0.07	Massive.
W.	9.2	0.08	Massive.	W.	13.0	0.07	Massive.
N.	9.6	0.11	Long.	N.	13.0	0.06	Ordinary.
W.	9.6	0.08	Massive.	N.	13.0	0.05	Flat, spinner.
N.	9.8	0.11	Massive.	N.	13.0	0.04	Ordinary.
N.	10.0	0.14	Long.	W.	13.2	0.07	Massive.
N.	10.0	0.07	Ordinary.	W.	13.2	0.06	Massive.
W.	10.2	0.09	Massive.	N.	13.4	0.05	Irregular.
W.	10.4	0.09	Irregular.	W.	13.6	0.07	Irregular, flat.
W.	10.4	0.07	Massive.	W.	13.6	0.05	Massive.
N.	10.4	0.06	Ordinary.	W.	13.6	0.05	Lump.
N.	10.6	0.07	Ordinary.	W.	13.8	0.15	Long, spinner.
N.	10.6	0.04	Ordinary.	N.	13.8	0.10	Flat, massive, spinner.
W.	10.8	0.09	Irregular.	W.	13.8	0.08	Long.
W.	10.8	0.09	Massive.	W.	14.0	0.13	Long.
N.	11.0	0.12	Ordinary.	W.	14.0	0.09	Flattish.
N.	11.0	0.11	Massive.	N.	14.0	0.08	Long.
N.	11.0	0.11	Massive.	N.	14.0	0.08	Long.
W.	11.0	0.07	Ordinary.	W.	14.0	0.06	Massive.
N.	11.2	0.14	Long, irregular, twister.	W.	14.0	0.05	Irregular.
N.	11.2	0.06	Ordinary.	W.	14.0	0.05	Massive.
N.	11.2	0.06	Ordinary.	N.	14.0	0.05	Irregular, flat.
N.	11.2	0.05	Long.	N.	14.0	0.04	Irregular.
W.	11.4	0.10	Irregular.	W.	14.2	0.08	Flat.
N.	11.4	0.08	Irregular.	N.	14.2	0.04	Ordinary.
N.	11.4	0.05	Ordinary.	N.	14.2	0.03	Ordinary.
N.	11.4	0.05	Massive.	N.	14.4	0.10	Long.
W.	11.8	0.14	Irregular.	W.	14.8	0.18	Long, flat.
N.	11.8	0.12	Flat, massive.	W.	14.8	0.07	Flat, wabbler.
N.	11.8	0.09	Ordinary.	N.	14.8	0.06	Long, flat.
N.	11.8	0.10	Long.	W.	14.8	0.04	Massive.
N.	11.8	0.08	Irregular.	W.	15.0	0.08	Long.
W.	11.8	0.08	Irregular.	W.	15.0	0.05	Massive.
W.	11.8	0.07	Ordinary.	N.	15.0	0.04	Ordinary.
W.	11.8	0.06	Ordinary.	W.	15.0	0.03	Flat.
W.	12.0	0.11	Flat.	W.	15.2	0.03	Irregular.
W.	12.0	0.07	Massive.	W.	15.4	0.07	Flat, spinner.
N.	12.0	0.06	Ordinary.	W.	15.8	0.04	Irregular, flat.
N.	12.0	0.06	Ordinary.	W.	16.0	0.06	Flat, wabbler.
W.	12.2	0.08	Massive.	N.	16.2	0.12	Long, massive, flat.
W.	12.2	0.08	Massive.	N.	16.4	0.07	Long, flat.
W.	12.2	0.06	Massive.	N.	17.2	0.08	Flat, wabbler.
N.	12.2	0.05	Ordinary.	W.	17.4	0.04	Flat.
W.	12.4	0.13	Irregular.	W.	18.0	0.13	Long.
W.	12.4	0.10	Long.	N.	18.2	0.05	Flat, spinner.
W.	12.4	0.07	Flattish.	N.	18.4	0.04	Long, flat, spinner.
				N.	18.6	0.05	Flat, twister.
				W.	20.0	0.06	Long, thin, wabbler.
				W.	20.0	0.05	Irregular, flat, spinner.
				N.	20.8	0.06	Long, twister.
				N.	21.0	0.03	Flat.
				W.	21.2	0.03	Flat.
				N.	22.2	0.03	Very flat.
				N.	22.6	0.05	Long, flat, spinner.
					13.5	0.07	Average.

and IV.) is supposed to be due to the fact that these were all selected grains, while those of the former were taken at random.

The behavior of the grains in falling is thus defined: "wabbler," one that has a zigzag course; "twister," one that descends in a helical path; "spinner," one that descends in the center but rotates rapidly as it goes. The rest of the grains dropped approximately in a straight line.

The letters "N" and "W," in the first column of Tables V. and VI., stand for Nagel and Warren.

III. The Second, or the Middle, Section of the Field.

The next section of the field was covered by Messrs. G. A. Barnaby and Ralph Hayden. Their sieves are given in Table VII. The sizes were measured by Mr. Robert F. Manahan by microscope and micrometer scale, adopting the mean of a number of observations.

Table VII.—*Double Rittinger Sieve-Scale Used by Barnaby and Hayden.*

	Diameter of Grains, mm.		
Double Rittinger.	Through mm.	On mm.	Average mm.
2.38	2.49	2.06	2.28
2.00	2.06	1.63	1.85
1.681	1.63	1.46	1.55
1.414	1.46	1.27	1.37
1.189	1.27	1.10	1.19
1.000	1.10	0.97	1.04
0.841	0.97	0.84	0.91
0.707	0.84	0.68	0.76
0.595	0.68	0.57	0.63
0.500	0.57	0.45	0.51
0.4205	0.45	0.36	0.41
0.3535	0.36	0.28	0.32
0.25			

It will be noted that the sieves do not correspond exactly with the double Rittinger scale, but the intervals between the sizes in the Tyler sieves which were used are so nearly the same as the double Rittinger that the purpose of the investigation was fully met by these sieves.

The test-tube adopted for these smaller grains was a glass tube, Fig. 2, 51.8 in. high and 2¼ in. in diameter, on which two courses were laid out, one 1 m. long, the other 0.5 m. long.

The distance from the top of the tube to the first sight for both courses was 4½ inches.

All the galena grains and the quartz grains between 2.49 mm. and 0.97 mm. were dropped through the 1-m. course. The quartz grains from 0.97 to 0.28 were dropped through the 0.5 m., and the figures for these last results were multiplied by 2 in order to place them all on a uniform basis in the table. The results of these tests are given in Tables VIII. and IX., and the final summing-up of them in Table XI. The figures given at the foot of the column of seconds are the average seconds for the 100 grains. As the same observer timed the starts and finish in this field, there is no error due to lag to be corrected in Table XI.

Warren drew curves of distribution of grains according to the velocity, which might have some significance, and found a bunch of grains among the quicker speeds and another among the slower. It may be that something can be found here; but Barnaby's results differ in showing for the coarser sizes of his crushing that the grains are largely bunched at one place, while for the smaller sizes they may be bunched at one or more places. I do not feel that anything sufficiently definite has been found upon which to base conclusions.

IV. The Third, or Finest, Section of the Field.

The tests of Barnaby and Hayden carry the measures of velocity of settling down to the limit of sifting—namely, 0.28-mm. grains.

Mr. E. S. Bardwell took up the work at this point, using the elutriation method. This consists of stirring up the grains in water, settling for a specified time and distance, and decanting the water with the suspended grains; then measuring the diameters of the decanted grains by a microscope and micrometer; and finally repeating the operation for a complete series.

Before proceeding with the determination of the velocity, it was necessary to crush samples of galena and quartz. Bardwell put 500 g. of each through the Hendrie and Bolthoff sample-grinder, starting with grains 2.83 mm. in diameter and bringing them down to pass through a 0.45-mm. screen. This was chosen a little larger than the 0.28-mm. screen of Barnaby and

TABLE VIII.—*Seconds of Time for Galena Grains to Drop through 1 Meter.*

Through 2.49 mm. On 2.06 mm. Aver. Diam., 2.28 mm.

Secs.	No. of Grs.
1.8	12
2.0	25
2.2	25
2.4	18
2.6	10
2.8	4
3.0	2
3.2	2
3.4	1
3.6	1
2.264	100

Through 2.06 mm. On 1.68 mm. Aver. Diam., 1.85 mm.

Secs.	No. of Grs.
1.8	1
2.0	1
2.2	12
2.4	21
2.6	20
2.8	18
3.0	14
3.2	5
3.4	4
3.6	2
3.8	0
4.0	0
4.2	1
4.4	1
2.704	100

Through 1.68 mm. On 1.46 mm. Aver. Diam., 1.55 mm.

Secs.	No. of Grs.
2.4	7
2.6	16
2.8	28
3.0	20
3.2	6
3.4	9
3.6	5
3.8	4
4.0	2
4.2	0
4.4	0
4.6	1
4.8	1
5.0	0
5.2	0
5.4	1
3.026	100

Through 1.46 mm. On 1.27 mm. Aver. Diam., 1.3 mm.

Secs.	No. of Grs.
2.6	5
2.8	14
3.0	20
3.2	16
3.4	14
3.6	9
3.8	7
4.0	3
4.2	4
4.4	0
4.6	4
4.8	1
5.0	1
5.2	0
5.4	0
5.6	0
5.8	1
6.0	1
3.388	100

Through 1.27 mm. On 1.10 mm. Aver. Diam., 1.19 mm.

Secs.	No. of Grs.
2.8	3
3.0	12
3.2	14
3.4	17
3.6	12
3.8	12
4.0	9
4.2	5
4.4	4
4.6	4
4.8	3
5.0	1
5.2	1
5.4	1
5.6	2
3.700	100

Through 1.10 mm. On 0.97 mm. Aver. Diam., 1.04 mm.

Secs.	No. of Grs.
2.8	1
3.0	3
3.2	10
3.4	12
3.6	16
3.8	11
4.0	14
4.2	4
4.4	8
4.6	9
4.8	2
5.0	3
5.2	4
5.4	1
5.6	1
5.8	0
6.0	0
6.2	1
3.960	100

Through 0.97 mm. On 0.84 mm. Aver. Diam., 0.91.

Secs.	No. of Grs.
3.2	2
3.4	5
3.6	10
3.8	14
4.0	9
4.2	11
4.4	11
4.6	7
4.8	6
5.0	10
5.2	5
5.4	1
5.6	3
5.8	2
6.0	2
6.2	0
6.4	0
6.6	1
6.8	1
4.398	100

Through 0.84 mm. On 0.68 mm. Aver. Diam., 0.76 mm.

Secs.	No. of Grs.
3.6	6
3.8	7
4.0	10
4.2	5
4.4	15
4.6	12
4.8	11
5.0	6
5.2	5
5.4	3
5.6	3
5.8	4
6.0	5
6.2	1
6.4	2
6.6	1
6.8	2
7.6	1
9.2	1
4.814	100

Through 0.68 mm. On 0.57 mm. Aver. Diam., 0.63 mm.

Secs.	No. of Grs.
3.8	1
4.0	2
4.2	6
4.4	10
4.6	8
4.8	11
5.0	14
5.2	8
5.4	11
5.6	5
5.8	9
6.0	5
6.2	3
6.4	0
6.6	3
6.8	1
7.0	2
7.2	1
5.182	100

Through 0.57 mm. On 0.45 mm. Aver. Diam., 0.51 mm.

Secs.	No. of Grs.
4.2	1
4.4	1
4.6	3
4.8	3
5.0	6
5.2	7
5.4	7
5.6	10
5.8	7
6.0	7
6.2	6
6.4	9
6.6	5
6.8	3
7.0	4
7.2	5
7.4	3
7.6	4
7.8	1
8.0	2
8.2	0
8.4	3
8.6	1
9.2	1
12.2	1
6.234	100

Through 0.45 mm. On 0.36 mm. Aver. Diam., 0.41 mm.

Secs.	No. of Grs.
5.6	1
6.2	6
6.4	8
6.6	3
6.8	6
7.0	8
7.2	8
7.4	10
7.6	4
7.8	7
8.0	4
8.2	3
8.4	2
8.6	3
8.8	3
9.0	1
9.2	2
9.4	6
9.6	3
9.8	2
10.0	3
10.2	1
10.4	2
10.6	1
11.6	2
13.4	1
7.932	100

Through 0.36 mm. On 0.28 mm. Aver. Diam., 0.32 mm.

Secs.	No. of Grs.
6.6	1
6.8	1
7.0	2
7.2	5
7.4	2
7.6	5
7.8	2
8.0	4
8.2	5
8.4	4
8.6	4
8.8	5
9.0	5
9.2	1
9.4	4
9.6	4
9.8	4
10.0	5
10.2	5
10.4	6
10.6	3
10.8	4
11.0	2
11.2	1
11.4	2
11.8	2
12.0	1
12.4	1
12.8	1
13.0	2
13.4	1
13.6	2
13.8	1
14.4	1
15.0	1
18.2	1
9.694	100

Hayden in order that his work should overlap a little on theirs, and that no gap should be left between the sifted and the floated grains.

Two designs of apparatus were made by Bardwell. That for slower speeds, Fig. 3, consisted of a bottle, *a*, with the bot-

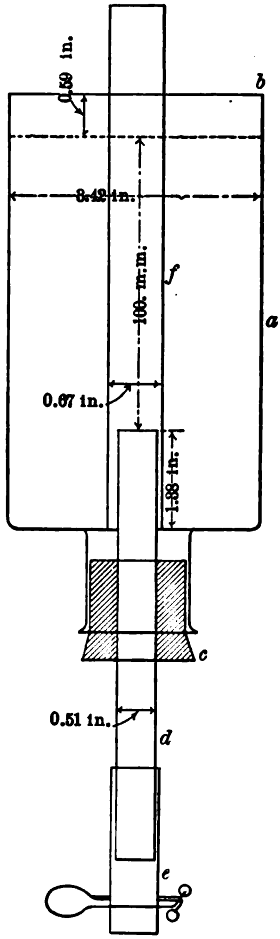


FIG. 3.—SORTING-BOTTLE FOR THE SLOWER GRAINS OF THE FINEST GROUP.

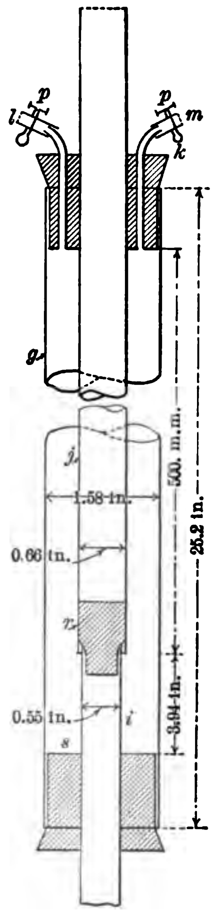


FIG. 4.—SORTING-TUBE FOR THE QUICKER GRAINS OF THE FINEST GROUP.

tom cut off at *b*, a cork stopper, *c*, a discharge-pipe, *d*, a rubber tube and pinch-cock, *e*, a glass guard-tube, *f*, and an upper sight 100 mm. above the end of the discharge-tube. The mode of operating was as follows: The sand (30 g. for quartz, 100 g. for galena) was charged, stirred up thoroughly with a

TABLE IX.—*Seconds of Time for Quartz*

Through 2.49 mm. On 2.06 mm. Aver. Diam., 2.28 mm.		Through 2.06 mm. On 1.68 mm. Aver. Diam., 1.85 mm.		Through 1.68 mm. On 1.46 mm. Aver. Diam., 1.55 mm.		Through 1.46 mm. On 1.27 mm. Aver. Diam., 1.37 mm.		Through 1.27 mm. On 1.10 mm. Aver. Diam., 1.19 mm.		Through 1.10 mm. On 0.97 mm. Aver. Diam., 1.04 mm.	
Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.	Secs.	No. of Grs.
4.2	2	4.4	2	5.2	1	5.8	1	6.4	2	6.8	1
4.4	2	4.6	0	5.4	0	6.0	0	6.6	1	7.0	0
4.6	2	4.8	1	5.6	1	6.2	0	6.8	0	7.2	0
4.8	7	5.0	3	5.8	4	6.4	4	7.0	2	7.4	2
5.0	11	5.2	8	6.0	9	6.6	4	7.2	2	7.6	1
5.2	14	5.4	6	6.2	5	6.8	5	7.4	6	7.8	0
5.4	7	5.6	8	6.4	4	7.0	4	7.6	7	8.0	3
5.6	6	5.8	5	6.6	5	7.2	8	7.8	3	8.2	1
5.8	5	6.0	10	6.8	3	7.4	4	8.0	8	8.4	6
6.0	8	6.2	10	7.0	6	7.6	6	8.2	7	8.6	5
6.2	9	6.4	8	7.2	7	7.8	3	8.4	1	8.8	4
6.4	3	6.6	5	7.4	3	8.0	6	8.6	3	9.0	1
6.6	5	6.8	9	7.6	8	8.2	7	8.8	5	9.2	2
6.8	1	7.0	4	7.8	3	8.4	7	9.0	6	9.4	5
7.0	7	7.2	4	8.0	8	8.6	7	9.2	2	9.6	5
7.2	0	7.4	4	8.2	5	8.8	4	9.4	5	9.8	6
7.4	3	7.6	4	8.4	3	9.0	3	9.6	2	10.0	6
7.6	1	7.8	0	8.6	2	9.2	3	9.8	3	10.2	4
7.8	0	8.0	5	8.8	1	9.4	2	10.0	2	10.4	5
8.0	1	8.2	1	9.0	2	9.6	4	10.2	2	10.6	5
8.2	0	8.4	2	9.2	2	9.8	1	10.4	2	10.8	5
8.4	0	8.6	0	9.4	0	10.0	3	10.6	3	11.0	0
8.6	0	8.8	4	9.6	2	10.2	3	10.8	2	11.2	4
8.8	1	9.0	0	9.8	0	10.4	2	11.0	4	11.4	3
9.0	0	9.2	0	10.0	6	10.6	2	11.2	2	11.6	0
9.2	0	9.4	1	10.2	2	10.8	0	11.4	3	11.8	1
9.4	0	9.6	2	10.4	0	11.0	1	11.6	1	12.0	1
9.6	1	9.8	0	10.6	0	11.2	1	11.8	0	12.2	5
9.8	0	10.0	0	10.8	1	11.4	0	12.0	3	12.4	0
10.0	0	10.2	0	11.0	0	11.6	1	12.2	1	12.6	0
10.2	0	10.4	0	11.6	3	11.8	1	12.4	3	12.8	1
10.4	1	10.6	0	11.8	1	12.0	1	12.6	0	13.0	6
10.6	1	10.8	1	12.0	1	12.2	1	12.8	0	13.2	2
10.8	0	11.0	0	13.4	1	14.4	1	13.0	0	13.4	2
11.0	1	11.2	1	14.6	0	8.440	100	13.2	1	13.6	1
11.2	1	11.4	0	14.8	1			13.4	1	13.8	2
5.994	100	11.6	1	7.866	100			13.6	1	14.0	0
(average)		14.0	1					14.2	1	14.2	1
		6.830	100					14.4	1	14.4	0
								14.6	1	14.6	1
								15.2	1	14.8	0
								9.472	100	15.6	1
										17.0	1
										18.2	1
										10.596	100

glass rod, and allowed to settle the specified time. (See Table X.) The guard-tube was then lifted out, and at the same time the discharge-cock was opened, decanting off the top water. After this had been done five times, about all the light grains had been removed from the heavy. Theoretically, 0.12 per cent. of the fine grains would remain with the coarse.

The second apparatus, Fig. 4, consisted of a glass settling-tube, g, a cork stopper, a glass discharging-tube, i, a stopper, r,

Grains to Drop through 1 *Meter.*

Through 0.97 mm. On 0.84 mm Aver. Diam., 0.91 mm.	
Secs.	No. of Grs.
8.2	3
8.8	3
9.2	9
9.6	10
10.0	9
10.4	3
10.8	11
11.2	3
11.6	6
12.0	3
12.4	4
12.8	7
13.2	3
13.6	4
14.0	4
14.4	2
14.8	7
15.2	0
15.6	2
16.0	3
16.4	0
16.8	3
23.2	1
11.834	100

Through 0.84 mm. On 0.68 mm. Aver. Diam., 0.76 mm.	
Secs.	No. of Grs.
8.8	1
9.2	4
9.6	3
10.0	8
10.4	3
10.8	9
11.2	6
11.6	9
12.0	8
12.4	2
12.8	4
13.2	5
13.6	6
14.0	3
14.4	5
14.8	3
15.2	1
15.6	2
16.0	3
16.4	1
16.8	3
17.2	2
17.6	3
18.0	0
18.4	1
18.8	2
19.2	0
19.6	0
20.0	0
20.4	1
20.8	1
24.8	1
13.028	100

Through 0.68 mm. On 0.57 mm. Aver. Diam., 0.63 mm.	
Secs.	No. of Grs.
10.8	1
11.2	1
11.6	5
12.0	7
12.4	5
12.8	5
13.2	8
13.6	11
14.0	9
14.4	5
14.8	6
15.2	5
15.6	5
16.0	3
16.4	3
16.8	4
17.2	3
17.6	3
18.0	3
18.4	2
18.8	0
19.2	1
19.6	0
20.0	0
20.4	1
20.8	0
22.4	1
22.8	1
26.0	1
27.6	1
14.840	100

Through 0.57 mm. On 0.45 mm. Aver. Diam., 0.51 mm.	
Secs.	No. of Grs.
12.0	1
12.4	1
12.8	1
13.2	1
13.6	3
14.0	2
14.4	1
14.8	1
15.2	3
15.6	5
16.0	6
16.4	6
16.8	5
17.2	6
17.6	6
18.0	8
18.4	3
18.8	4
19.2	6
19.6	2
20.0	3
20.4	1
20.8	3
21.2	1
21.6	2
22.0	2
22.4	3
22.8	2
23.2	1
23.6	1
24.8	1
26.8	1
27.2	1
27.6	0
28.0	2
28.4	1
29.6	1
31.6	1
36.8	1
38.0	0
38.4	1
18.986	100

Through 0.45 mm. On 0.36 mm. Aver. Diam., 0.41 mm.	
Secs.	No. of Grs.
16.4	1
16.8	1
17.2	1
17.6	0
18.0	2
18.4	1
18.8	1
19.2	2
19.6	5
20.0	3
20.4	2
20.8	7
21.2	3
21.6	3
22.0	4
22.4	3
22.8	5
23.2	4
23.6	5
24.0	6
24.4	3
24.8	5
25.2	1
25.6	3
26.0	2
26.4	2
26.8	4
27.2	1
27.6	0
28.4	2
28.8	1
29.4	1
29.6	1
30.0	1
31.2	1
31.6	4
32.0	3
32.8	2
33.6	1
34.8	1
37.6	2
24.346	100

Through 0.36 mm. On 0.28 mm. Aver. Diam., 0.32 mm.	
Secs.	No. of Grs.
20.8	1
21.2	3
21.6	1
22.0	0
22.4	1
22.8	1
23.2	4
23.6	2
24.0	2
24.8	1
25.2	6
25.6	2
26.0	3
26.4	4
26.8	3
27.2	2
27.6	1
28.0	3
28.4	4
29.6	2
30.0	3
30.4	3
30.8	2
31.2	2
31.6	3
32.0	3
32.4	4
32.8	4
33.6	1
34.0	3
34.4	4
34.8	1
37.6	1
38.0	1
38.4	1
39.2	4
40.8	1
41.2	1
41.6	2
42.0	1
42.4	1
42.8	4
44.8	1
45.2	1
55.6	1
64.8	1
31.360	100

with handle of glass tube, *j*, and a cork stopper, *k*, an air-vent, *l*, a water-entrance, *m*, and two pinch-cocks, *pp*. The method of using this was to put in the sand; adjust the plug, *r*, the handle, *j*, and the stopper, *k*; to admit water at *m*, and drive out air at *l*; next, to invert and mix the water and sand thoroughly together; then restore to working position. In this case the time for settling 500 mm. was recorded. When the grains had settled the required time, the cork, *k*, the

handle, j, and the stopper, r, were withdrawn and the water with its suspended sand was discharged. The plug, k, the handle, j, and the stopper, r, were then replaced, the tube refilled with water, inverted to bring the grains to the top of the tube, reversed to working position, timed again and discharged. This test performed five times gave in the discharged water about all the light grains, and at the bottom, s, of the tube, all the heavy grains. Theoretically, 0.014 per cent. of the light grains would remain with the heavy.

All the quartz grains were tested in the first apparatus, Fig. 3, but in testing the galena grains it was found that when the time became less than 4.5 seconds it was advisable to use the second apparatus (Fig. 4), which settles 500 mm. instead of 100 mm.

After the settling-apparatus was designed and the mineral crushed, it was necessary to decide on a scale of time for settling which would serve to divide the grains into groups for this part of the field in the same way that the sieves did for the two coarser fields. A grain of quartz, 0.35 mm. in diameter, which settles 100 mm. in 2.432 seconds, was taken as the starting-point, and the double Rittinger factor (1.189) was used to multiply the seconds of time; 2.432 seconds multiplied by 1.189 gave the second time-value, multiplied by 1.189^2 it gave the third, by 1.189^3 the fourth, and so on until 1.189^{36} gave 1082.6 seconds as the time for settling quartz 100 mm. This last gives grains small enough for the fine end of the series. Thus the complete series of times was adopted for quartz, as given in Table X. The series was made for galena in this way: A 0.36-mm. grain of galena settles 100 mm. in 0.7928 second; multiplied by 1.189 this gave the second time-value; by 1.189^2 gave the third, and so on until 1.189^{42} was reached and gave 1005.0 seconds as the settling-time for galena. This gives grains small enough for the small end of the series. This complete series of times was adopted for galena (Table X).

In conducting the experiments, one can keep the volumes of water of reasonable size by beginning with the small grains—that is, with those that have the slowest rate of settling. On this account the several tests were tried in the reverse order from that given in Table X.

Since the ten quickest groups of galena grains were treated

TABLE X.—*Double Rittinger Time-Scale Used by Bardwell.*

No. of Decantation.	100 mm. Quartz Seconds.	100 mm. Galena Seconds.	No. of Decantation.	100 mm. Quartz Seconds.	100 mm. Galena Seconds.
1	2.4	0.8	22	94.6	30.8
2	2.9	0.9	23	112.7	36.7
3	3.5	1.12	24	134.0	43.7
4	4.1	1.34	25	159.5	52.0
5	4.9	1.59	26	190.0	62.0
6	5.8	1.9	27	226.0	73.7
7	6.9	2.3	28	269.0	87.7
8	8.2	2.7	29	320.0	104.3
9	9.8	3.2	30	381.0	124.1
10	11.7	3.8	31	454.0	147.9
11	14.0	4.5	32	540.0	176.0
12	16.6	5.4	33	643.0	209.3
13	19.8	6.4	34	765.2	249.2
14	23.5	7.7	35	910.6	296.5
15	28.0	9.1	36	1082.6	353.0
16	33.3	10.8	37	....	420.0
17	39.7	12.9	38	....	500.0
18	47.1	15.4	39	....	595.0
19	56.1	18.3	40	....	709.0
20	66.8	21.8	41	....	844.0
21	79.5	25.9	42	....	1005.0

with 500-mm. settling-column, their time-values, as given in Table X., had to be multiplied by five for use in the tube.

The results of these measures are given in Table XI., and with them the corresponding velocities in mm. a second. These latter values are derived from the velocities, which are given in the table in seconds for 100 mm.

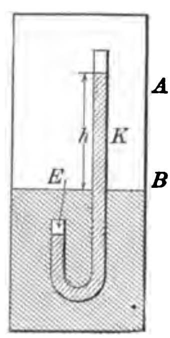


FIG. 5.—COLUMN OF WATER TO SUPPORT A CUBE OF MINERAL.

V. DISCUSSION OF RESULTS.

In Table XI. we have the summing-up of the work of all three fields recomputed to the uniform basis of mm. a second for velocity. We have also a mathematical computation of the rate of fall and the ratio between this theoretical and the actual rate of fall.

Discussing these results mathematically from the point of view taken by Rittinger, we have in Fig. 5: *A*, a jar with water in it up to *B*; *K*, a U-tube with a square section, which we will call D meters square inside section. Upon the lower end is a cube of mineral, *E*, D meters cube; and within the tube is a column, *h*, of water just high enough to balance the weight of the cube, *E*.

TABLE XI.—*Velocity of Settling of Particles of Galena and Quartz, under Free Settling Conditions.*

By Warren and Nagel—Average velocities are of 100 observations.

Diameters of grains Millimeters.			Galena Velocities.			Comp't Vel'cty V.	Ratio Average divided by Compt f.	Quartz Velocities			Comp Vel. V.	Ratio Average divided by Comp f.
Thro mm.	On mm.	Av. mm.	Max. mm. Sec.	Min. mm. Sec.	Aver. mm. Sec.	mm. Sec.		Max. mm. Sec.	Min. mm. Sec.	Aver. mm. Sec.	mm. Sec.	
12.85	11.01	11.93	1201.	647.	934.	1235.	0.7576	489.	271.	398.	621.5	0.6325
11.01	9.51	10.26	1016.	647.	865.	1142.	0.7576	489.	252.	361.	576.	0.6269
9.51	7.79	8.65	956.	678.	810.	1052.	0.7704	489.	231.	340.	532.	0.6390
7.79	6.85	7.32	895.	546.	729.	968.	0.7519	489.	227.	308.	487.5	0.6219
6.85	5.97	6.41	841.	506.	680.	906.	0.7512	416.	185.	289.	455.2	0.6349
5.97	4.95	5.46	793.	489.	631.	836.	0.7547	362.	172.	260.	421.	0.6173
4.95	4.21	4.58	713.	372.	558.	765.	0.7299	345.	158.	240.	385.	0.6242
4.21	4.12	4.17	678.	393.	538.	731.	0.7358	345.	154.	225.	368.	0.6116
4.12	2.83	3.48	647.	382.	513.	671.	0.7684	307.	154.	209.	338.2	0.6179
2.83	2.82	2.83	525.	344.	450.	607.	0.7407	256.	127.	191.	308.	0.6305
2.82	2.05	2.44	546.	321.	420.	557.	0.7535	252.	119.	168.	280.5	0.5988
By Barnaby and Hayden—Average velocities are of 100 observations.												
2.49	2.06	2.28	555.	278.	442.	539.5	0.8197	238.	89.	166.7	272.	0.6135
2.06	1.63	1.85	555.	227.	370.	486.	0.7622	227.	71.	146.6	244.5	0.5988
1.63	1.46	1.55	417.	185.	330.5	445.	0.7435	192.	68.	126.6	224.8	0.5634
1.46	1.27	1.37	384.	167.	295.1	418.	0.7067	173.	82.	118.4	218.2	0.5435
1.27	1.10	1.19	332.	179.	270.1	390.	0.6935	156.	69.	105.6	210.5	0.5082
1.10	0.97	1.04	332.	161.	252.5	364.	0.6944	147.	64.	94.5	203.5	0.4604
0.97	0.84	0.91	312.	147.	227.5	341.	0.6667	119.	43.	84.1	171.7	0.4902
0.84	0.68	0.76	278.	109.	207.8	311.5	0.6667	114.	40.	76.7	157.	0.4890
0.68	0.57	0.63	268.	139.	192.8	283.5	0.6788	89.	36.	67.2	146.	0.4608
0.57	0.45	0.51	238.	82.	160.4	255.	0.6329	78.	32.	52.7	129.	0.4090
0.45	0.36	0.41	179.	75.	126.1	229.	0.5495	61.	27.	41.2	115.2	0.3571
0.36	0.28	0.32	152.	55.	103.1	202.	0.5102	47.	15.	31.9	101.7	0.3135

By Bardwell, elutriation test—Average diameters are of 10 microscopic fields.

Galena Diam., mm.			Vel'c'ty	Compt Vel'c'y V.	Ratio Average divided by Comptd f.	Quartz Diameter, mm.			Vel'c'y	Compt Vel'c'y V.	Ratio Average divided by Compt f.
Largest	Smallest.	Average.	mm. per Second.	mm. Sec.		Largest.	Smallest.	Average.	mm. per Sec'nd	mm. Sec.	
0.480	0.138	0.345	125.	209.5	0.5970	0.509	0.243	0.369	41.67	109.5	0.3802
0.426	0.119	0.279	111.1	189.0	0.5882	0.418	0.163	0.305	34.48	99.5	0.4202
0.409	0.0764	0.215	88.5	165.8	0.5344	0.339	0.144	0.234	28.57	87.1	0.3279
0.321	0.0523	0.160	74.6	145.5	0.5128	0.321	0.130	0.199	24.39	80.4	0.3030
0.254	0.0445	0.127	62.9	127.2	0.4717	0.298	0.103	0.182	20.41	77.0	0.2653
0.215	0.0296	0.106	52.6	116.2	0.4717	0.254	0.0827	0.156	17.24	71.1	0.2427
0.201	0.0273	0.0967	43.5	111.0	0.3922	0.252	0.0655	0.135	14.49	66.1	0.2193
0.187	0.0242	0.0839	37.0	103.5	0.3571	0.249	0.0808	0.126	12.05	64.0	0.1883
0.165	0.0179	0.0798	31.3	100.1	0.3125	0.237	0.0679	0.121	10.20	62.7	0.1626
0.184	0.0157	0.0714	26.3	95.2	0.2762	0.219	0.0655	0.116	8.55	61.3	0.1396
0.115	0.0195	0.0667	22.2	92.3	0.2404	0.235	0.0569	0.112	7.14	60.3	0.1183
0.0879	0.0125	0.0599	18.5	87.9	0.2105	0.168	0.0608	0.0912	6.02	54.4	0.1111
0.0946	0.00884	0.0572	15.6	85.6	0.1821	0.158	0.0429	0.0846	5.05	52.4	0.0904
0.0853	0.00780	0.0535	13.0	82.6	0.1575	0.147	0.0414	0.0800	4.26	50.9	0.0840
0.0827	0.00832	0.0484	11.0	78.4	0.1403	0.120	0.0364	0.0747	3.57	49.3	0.0725
0.0684	0.00624	0.0437	9.26	74.6	0.1241	0.0972	0.0387	0.0689	3.00	47.3	0.0635
0.0764	0.00676	0.0419	7.75	73.1	0.1059	0.0970	0.0315	0.0629	2.52	45.1	0.0558
0.0741	0.00546	0.0401	6.49	71.6	0.0906	0.0918	0.0317	0.0555	2.12	42.4	0.0500
0.0653	0.00520	0.0390	5.46	70.6	0.0774	0.0842	0.0200	0.0503	1.78	40.4	0.0441
0.0552	0.00419	0.0354	4.59	67.2	0.0683	0.0718	0.0164	0.0478	1.50	39.4	0.0380
0.0499	....	0.0311	3.86	62.9	0.0614	0.0715	0.0138	0.0425	1.26	37.1	0.0340
0.0440	....	0.0284	3.25	60.2	0.0541	0.0660	0.0109	0.0377	1.06	35.0	0.0303
0.0431	....	0.0259	2.72	57.6	0.0478	0.0629	0.0109	0.0344	0.887	33.4	8.0265
0.0419	....	0.0235	2.29	55.4	0.0413	0.0611	0.00806	0.0319	0.746	32.1	0.0230
0.0408	....	0.0219	1.92	53.0	0.0362	0.0580	0.00962	0.0282	0.627	30.25	0.0207
0.0394	....	0.0205	1.61	51.7	0.0312	0.0548	0.00780	0.0267	0.526	29.45	0.0179
0.0301	....	0.0198	1.36	49.6	0.0274	0.0462	0.00868	0.0253	0.442	28.6	0.0155
0.0267	....	0.0176	1.14	47.4	0.0241	0.0462	0.00666	0.0232	0.372	27.4	0.0136
0.0305	....	0.0160	0.959	45.2	0.0212	0.0394	0.00419	0.0209	0.313	26.05	0.0120
0.0233	....	0.0149	0.806	43.6	9.0185	0.0408	0.00326	0.0188	0.262	24.7	0.0106
0.0193	....	0.0141	0.676	42.4	0.0159	0.0328	....	0.0182	0.220	24.3	9.00905
0.0230	....	0.0134	0.568	41.4	0.0137	0.0301	....	0.0161	0.185	22,85	0.00810
0.0226	....	0.0128	0.478	40.5	0.0118	0.0412	....	0.0144	0.156	21.6	0.00723
0.0173	....	0.0112	0.401	37.8	0.0106	0.0408	....	0.0126	0.131	20.1	0.00709
0.0167	....	0.00956	0.337	34.95	0.00965	0.0318	....	0.00884	0.110	16.91	0.00649
0.0166	....	0.00790	0.283	31.8	0.00890	0.0264	....	0.00589	0.0924	18.81	0.00668
0.0130	....	0.00700	0.238	29.9	0.00797	....	....	....	....	....	....
0.0124	....	0.00598	0.200	27.5	0.00727	....	....	....	....	....	....
0.0104	....	0.00498	0.168	25.1	0.00670	....	....	....	....	....	....
0.0117	....	0.00481	0.141	23.42	0.00597	....	....	....	....	....	....
0.0112	....	0.00380	0.118	20.52	0.00575	....	....	....	....	....	....
0.00745	....	0.00152	0.0995	18.91	0.00715	....	....	....	....	....	....

Then D is the width of the cube of mineral in meters.

δ is specific gravity of the mineral, 2.65 for quartz, 7.5 for galena.

h is the column of water to balance the grain.

$h = D(\delta - 1)$.

Rittinger assumes that because a column h meters high balances the weight of a stationary grain, therefore the velocity due to h, if rising, is able to prevent the grain from falling; or, in other words, it is the velocity of the fall of the grain. On this basis he tells us (p. 191) from the formula $V = \sqrt{2gh}$ when $g = 9.8024$ m., $\sqrt{2g} = 4.42773$ m., that the velocity V of settling in water of grains of minerals is

$$V = C\sqrt{D(\delta - 1)}$$

where C is a constant.

$$C = 2.44 \text{ for average grains,}$$
$$2.73 \text{ for roundish grains,}$$
$$2.37 \text{ for long grains,}$$
$$1.92 \text{ for flat grains.}$$

Rittinger's C seems to be made up of $f\sqrt{2g}$ where f is a factor due to friction.

In Table XI. the column marked "Computed velocity" is obtained from Rittinger's formula $V = \sqrt{2g}\sqrt{D(\delta - 1)}$, omitting the f. In the column marked "Ratio of computed divided by average," we have a value for f. The value of this factor is practically constant for grains larger than 1.55 mm. in diameter. For galena it is 0.7558; for quartz, 0.6157. But for grains smaller than 1.55 mm. in diameter the value of f decreases in a most extraordinary degree. This discrepancy between the values shows that Rittinger's universal formula for all minerals is not universal, and that it needs some added factor which will provide for the differences in specific gravity. This may be overcome for practical purposes by simply determining the factors for different specific gravities, as has been done above for quartz and galena.

Mr. G. W. Eastman has kindly made a study of this question, and his line of argument with his conclusions is here given.

In Fig. 6, two curves for quartz and galena were drawn from the average diameters and velocities by using logarithms

of the numbers instead of the numbers themselves. The abscissas are the logarithms of D, the ordinates are the logarithms of V. The advantage of the logarithmic curve is its compactness and the ease with which the formulas can be derived from it. A curve made from natural numbers would be many feet long.

The curves show at once two things: that they are practically parallel, and that they are divided in the main into two parts.

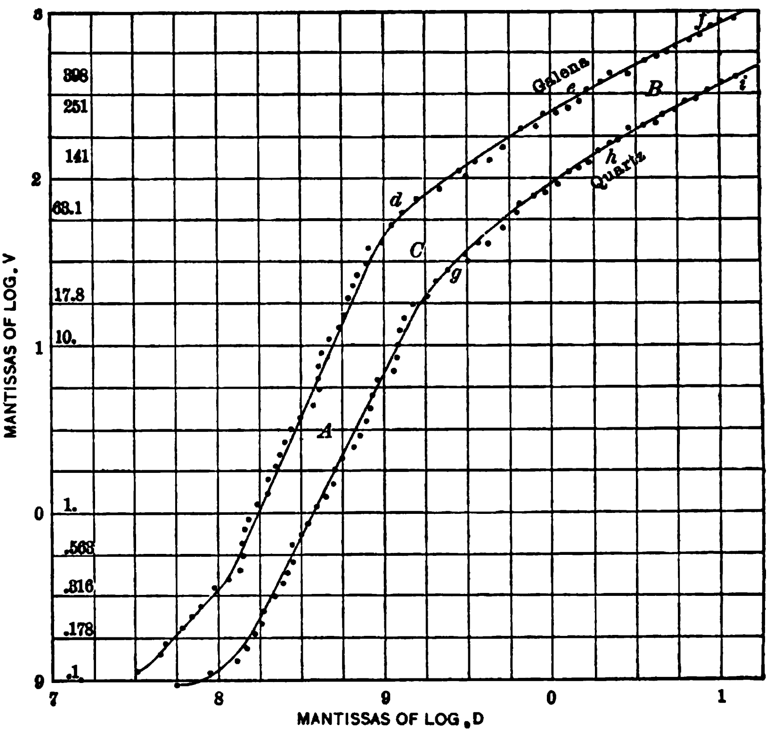


FIG. 6.—LOGARITHMIC CURVES OF AVERAGE VELOCITIES AND DIAMETERS OF THE COMPLETE SERIES.

The points for the smaller grains, which follow one law (the Law of Viscous Resistance), are on a straight line, *A*. The points for the larger grains, which follow another law (the Law of Eddying Resistance), are also on a nearly straight line, *B*. Between the two lines, *A* and *B*, is the critical or transition space, *C*.

The derivation of the Law of Viscous Resistance is as follows:

For the case of a small sphere falling slowly through a viscous fluid, Sir G. G. Stokes[2] has deduced from purely theoretical considerations for the terminal velocity, V, of the sphere the following formula:

$$V = \frac{2}{9}\, g \left(\frac{\delta - \delta'}{n}\right) r^2$$

where r = radius of the sphere,
g = acceleration due to gravity,
δ = density of the sphere,
δ' = density of the fluid,
n = the co-efficient of viscosity or "inner friction" of the fluid,

the quantities all being expressed in c-g-s. (centimeter-gram-second) units.

For water at 20° C. $\delta' = 1$, and $n = 0.010$; hence the formula would become

$$V = K\,(\delta - 1)\,D^2, \qquad \text{(A)}$$

where the constant K should theoretically be the same (about 550) for particles of all densities; but since it involves n, it would change about 2 per cent. per degree for temperatures different from 20° C.

If V and D are taken in millimeters instead of V and r in centimeters, the formula becomes, by substituting known quantities,

$$\left(\frac{V}{10}\right) = \frac{2}{9}\; 0.981 \left(\frac{\delta - 1}{0.01}\right) \left(\frac{D}{2 \times 10}\right)^2,$$

or $V = 545\,(\delta - 1)\,D^2$.

For a given substance $(\delta - 1)$ would also be constant; so we should expect to find that the velocity of settling would be simply a constant times the square of the diameter of the particle, or

$$V = K'\,D^2, \text{ where } K' = K\,(\delta - 1),$$

or taking logs., we have

$$\log.\ V = \log.\ K' + 2 \log.\ D.$$

That such a simple law is followed closely by both quartz and galena is shown very clearly by reference to the logarith-

[2] *Mathematical and Physical Papers*, vol. iii., p 60 (1901).

mic plots, Fig. 6. The points on the lines *A* lie very strikingly on a straight line, whose slope is nearly 2 : 1; that is, log. V is increasing just twice as rapidly as log. D, as it should, according to the formula above. The value of log. K′ is the intercept on the V axis (that is, the value of log. V when log. D = 0), from which we get readily the values for K′—namely, 700 for quartz and 4100 for galena. The corresponding values for K in formula (A) would be

$$K = \frac{700}{(2.65 - 1)} = 424 \text{ for quartz,}$$

$$\text{and } K = \frac{4100}{(7.5 - 1)} = 631 \text{ for galena,}$$

values which differ considerably, it is true, but which lie on either side of the theoretical value 550.

The derivation of the Law of Eddying Resistance is as follows: Stokes's equation is derived on the assumption of small velocity and a resistance due entirely to viscosity proper, and it is known not to hold above a certain "critical velocity" when the resistance due to eddying motion set up in the fluid becomes appreciable and important. For such high velocities a complete theory seems to be almost impossible; but Sir Isaac Newton pointed out that the resistance might be expected to vary as the square of the velocity. In other words, $R = kV^2$ where R is the resistance to motion, and k is a constant. Evidently when dynamic equilibrium is attained R is just equal to the effective weight of the particle in the liquid. The effective weight has been shown above to be $D(\delta - 1)$. Substituting this value $D(\delta - 1)$ for R in the equation above, we have

$$D(\delta - 1) = kV^2,$$

from which we get, by extracting the square root, Rittinger's formula:

$$V = C\sqrt{D(\delta - 1)} \qquad \text{(B)}$$

(using C outside the radical in place of $\frac{1}{k}$ inside).

We should expect this to hold only when Newton's law of

resistance is followed, and the results indicate that this is more nearly true, the greater the velocity; that is, when the true viscous resistance plays a continuously less important part, and the eddying resistance an increasingly important part.

The existence of the "critical velocity" and the transition from the Law of Viscous Resistance (A) to the very different Law of Eddying Resistance (B) is strikingly shown on the plot by the decided change in the slope of the lines for both quartz and galena between the lines *A* and *B*. Actually the slope for both quartz and galena does become about $\frac{1}{2}$ from *e* to *f* and from *h* to *i*. The formulas thus indicated are: for quartz, $V = 113\sqrt{D}$, and for galena, $V = 250\sqrt{D}$. (The data would be represented over a somewhat larger range, *g* to *i* and *d* to *f*, by the formulas $V = 89\ D^{0.67}$, for quartz; $V = 240\ D^{0.75}$, for galena.)

Bringing in the specific gravities (in other words, finding C for the Rittinger formula), would change these two expressions into $V = 87\sqrt{(\delta - 1)D}$, for quartz, and $V = 100\sqrt{(\delta - 1)D}$, for galena. (The constants 87 and 100 would correspond to 2.7 and 3.2 in Rittinger's formula, when V and D are expressed in meters instead of in millimeters.)

We see again a distinct individuality in the constants for the two substances.

The critical velocities are apparently about 63 mm. a second for galena and 28 mm. for quartz, and the corresponding critical diameters are about 0.13 mm. for galena and 0.20 for quartz. Of course, in this neighborhood, neither of the derived formulas will apply very closely. Owing to the decided change here, a simple formula to cover the entire range seems quite out of the question.

It will be noticed that the four or five observations on the smallest galena particles lie a little off the line *A*, as do also two observations on quartz. It is difficult to see why these cases should deviate from Stokes's law, unless the already very slow settling of the particles is made apparently still slower by slight currents in the water, due to temperature changes, which would be almost unavoidable outside of a well-regulated thermostat or chamber supplied with means of maintaining a constant temperature. An empirical formula could be made to fit these few observations, but it seems hardly necessary. In fact,

the values of the velocity over the whole range can be read off from the plot as accurately and more readily than they could be computed from the formulas.

One interested in the theory of the motion of a solid through a liquid will find a brief summary in Poynting and Thomson's *Text Book of Physics*, ed. 1902, page 221; and a more complete discussion, including some interesting work on the rate of rising of bubbles and spheres lighter than water, by H. S. Allen, *Philosophical Magazine*, September and November, 1900. Both references have been freely used in preparing the above.

VI. Summary.

The above discussion of the experiments thus indicates that two quite different laws are followed by settling particles, depending on whether the velocity is above or below a certain transition or critical point. Below this critical velocity the law is expressed by the formula:

$$V = K(\delta - 1)D^2 \qquad \text{(A)}$$

and above this critical velocity the law is expressed by the formula of Rittinger,

$$V = C\sqrt{D(\delta - 1)}. \qquad \text{(B)}$$

The values of K indicated by our experiments are 424 for quartz and 631 for galena; and the values for C are 87 for quartz and 100 for galena.

I believe that in this paper the mineral-dresser will find aid to a solution of his problems when size of grain and velocity of fall are under consideration. For, if he has other minerals than quartz and galena to deal with, he can assume that the velocity of grains of those minerals will be proportional to their specific gravity. This is approximately true, and nearly enough so for all mill purposes.

I wish to give especial credit to Mr. Warren for his good work in planning and executing his part of this paper.

SUBJECT TO REVISION.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Mining Operations in New York City and Vicinity.

BY H. T. HILDAGE, NEW YORK, N. Y.*

(New York Meeting, April, 1907.)

ALTHOUGH Greater New York does not bear any resemblance to a great mining district, the mining operations that are being conducted in and about the city are both extensive and interesting in character.

With regard to the extent, it may be mentioned that, at present, there is more dynamite used in New York than in any mining district in the United States; that there are under construction about 38 miles of tunnel, and that 66 miles more are projected, most of which must be constructed in the near future; that since 1902 at least 2,000,000 tons of earth has been removed in underground work, in addition to about 3,500,000 tons that has been removed in open-cut in connection with tunnel-work, and many times this quantity that has been removed in excavating foundations for buildings not connected with tunnel-work; and that there are to-day probably more than 5,000 men engaged in mining-work in and about New York City.

These undertakings include almost every operation connected with underground work, from exploration by means of trench and boring, to the sinking of large shafts and the driving of large tunnels through every kind of ground from hard rock to soft, semi-fluid silt and quicksand.

It is proposed in this paper to give a general description of some of the methods and appliances used in the opening-up of a "mine" in a large city, and a brief description of some of the "mines" now being developed in New York, connecting as far as possible the methods described with the particular work for which they were designed, in order to give a general idea of the

* Associate member of the Institution of Civil Engineers and associate member of the Institution of Mechanical Engineers.

work that is being done and the means by which it is accomplished. Fig. 1 shows the tunnels that are now under construction. A complete and detailed description of the tunnelwork that is being done and has been done in New York City during the last few years would form an important treatise on

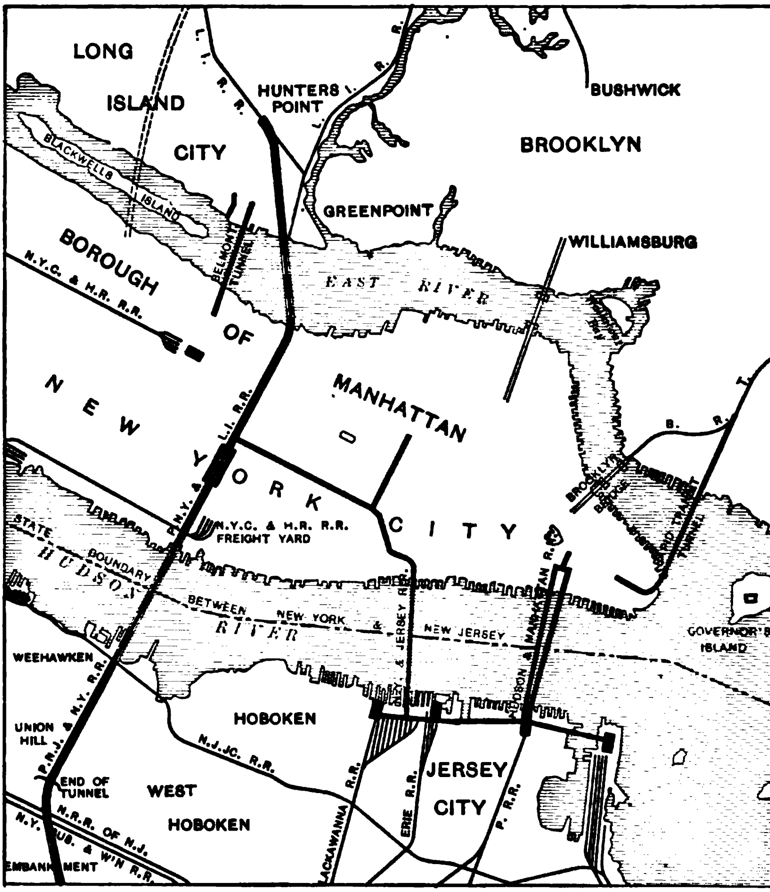


FIG. 1.—MAP SHOWING TUNNELS IN CONSTRUCTION IN NEW YORK AND VICINITY.

the art of soft-ground tunneling at least, and is entirely beyond the scope of this paper, which will, however, perhaps serve as an introduction to more complete papers recently published or to be published.

Location and Exploration.—Although the methods that are used in the exploration and development of a mine are essentially the same methods, perhaps somewhat specialized, as

those used in the location and construction of a tunnel, and although most tunnels when completed are expected to fulfill at least one important function of a mine, that of yielding more or less profit to its owners, the considerations that govern the location and the nature of the development-work of a mine are essentially different from the considerations that govern the location, depth, size and number of tunnels.

Generally speaking, the depth, direction and position of a tunnel are, unlike the workings of a mine, fixed quite independently of the nature of the ground. The avoidance of steep grades and sharp curves, and the entrance into a terminal that is located in a position suitable to the convenience of passengers and at a convenient level, are the ruling conditions in fixing the depth, direction and position of tunnels. When the tunnel engineer becomes connected with a contemplated work, all these factors are more or less fixed, and although he may have some discretion with regard to depth, he is usually called upon to drive a tunnel in a certain position regardless of the nature of the ground, and he cannot deviate very much from the line and level given to him in order to get into more suitable strata.

The exploration-work for a tunnel differs from the exploration-work of a mine, inasmuch as its object is to explore the ground within a very limited distance of a certain imaginary line and not to seek suitable strata. This work consists of sinking a number of wash- and core-borings and trial-pits on and near the approximately fixed center-line of the contemplated tunnel, of such depth as to give as full information as possible concerning the strata through which the tunnel must pass and upon which it must lie.

It is true, as in the case of a mine, that although this exploration-work is usually carefully considered and is often quite elaborate, it very often does not reveal some very important geological feature or has to be supplemented during the course of construction.

To take one example, 147 core- and 330 wash-borings of an aggregate depth of 23,000 ft. were made to explore the ground through which the Pennsylvania tunnels were to be driven, and subsequent work has shown these borings to have been accurately taken; yet the design of the work had to be modified in some important particulars because the ground through which the borings passed was not representative of the neighborhood;

and an additional series of borings has had to be taken from the interior of the tunnels under the North river for the purpose of exploring the ground lower down in order to discover suitable material for foundations. The design of the Weehawken shaft had to be radically changed, because in the course of excavation it was found that the contact of the trap of the Palisades and the sandstone occurred at this point. The methods of construction of the tunnels across Manhattan were modified for similar reasons. It was originally intended to tunnel from 9th avenue to 11th avenue without disturbing the surface of the ground, as the borings apparently indicated that the rock-cover was sufficient but not very heavy. It was found, however, that the rock-roof thinned out and in places disappeared, and on this account it was decided to build the tunnel by cut-and-cover methods.

When all the borings have been taken along the line of a tunnel about to be built, the center-line and grades are definitely decided upon, and, if it has not already been done, the position of the shafts is fixed and the sinking is commenced.

Shafts.—The first shaft, Fig. 2, sunk for the Hudson tunnel, in Jersey City, was of brick and about 28 ft. in diameter. It appears that the location of this shaft was chosen mainly in order to make the tunnel as short as possible. Consequently, it was built entirely in soft ground. An air-lock was built in the side of the shaft and tunneling started from there, but while the connection between the shaft and the tunnel was being completed and made safe, an accident happened that disabled this air-lock and shut off access to the tunnel. A timber caisson, Fig. 2, was then sunk alongside the shaft, and by means of this the two single-track tunnels were commenced and safely connected with the shaft, which was used for all subsequent work. The Morton street (New York) shaft for the same tunnel was a timber caisson 27 ft. 6 in. by 46 ft., and 26 ft. deep from the top of the deck to the cutting edge. This caisson, entirely in soft water-bearing ground, spanned both tunnels.

Access to the tunnels of the Pennsylvania Railroad Co. was obtained at the portal on the Hackensack meadows and through shafts located in the following places: Weehawken, in the Erie yards, near Baldwin avenue; Manhattan, between 32d and 33d streets, at 11th avenue; at 32d and 33d streets (two shafts), between Fourth and Madison avenues; between 32d and 34th

streets, near First avenue; and Long Island City, one shaft in the river in Nassau slip, one on shore near the bulkhead, and others at East avenue and Borden avenue.

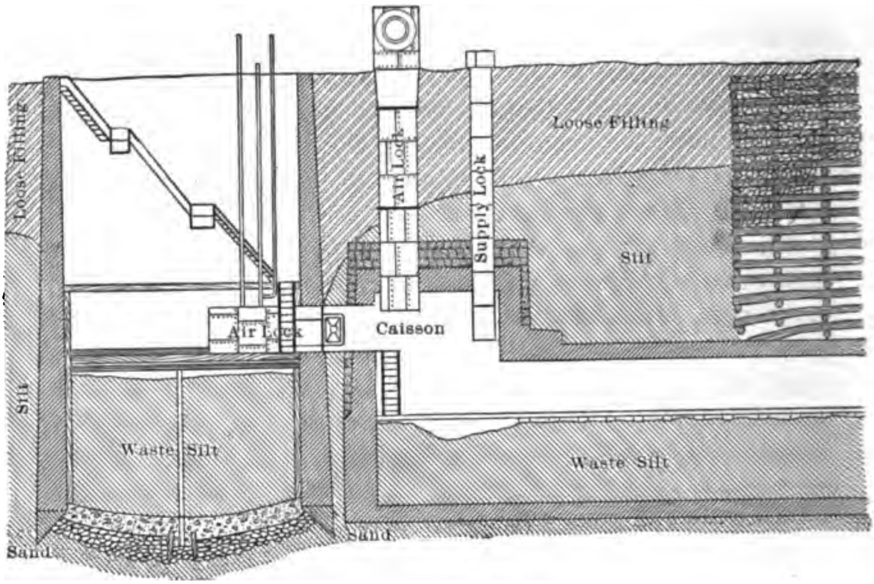
The considerations that fixed the positions of the river-shafts, apart from local conditions, were the desirability of shortening as much as possible the river-tunnels and of having them start out in good ground.

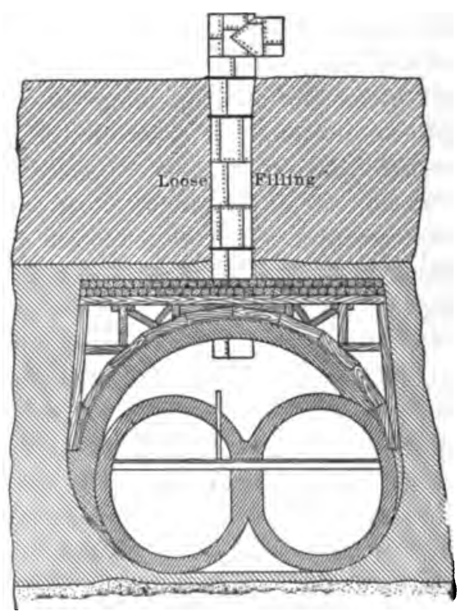
The Weehawken shaft of the Pennsylvania tunnel, 56 ft. by 115 ft. 9 in. at the bottom and 76 ft. deep, is lined with concrete from top to bottom. It is on the center-line of the tunnels. The ground is mostly rock. The Manhattan (North River) shaft, 22 ft. by 32 ft. and 55 ft. deep, is lined with concrete and steel down to the surface of the rock. It is about 100 ft. from the center-line between the tunnels, and is connected with them by a cross-heading. The upper part is in made ground, the lower part in rock.

The shafts between Fourth and Madison avenues, on 32d and 33d streets, 20 ft. by 30 ft. and 96 ft. deep, are not lined, being entirely in sound rock. They are 50 ft. from the tunnels they serve, and are connected therewith by cross-headings 20 ft. wide.

Each shaft for the East River tunnels serves two tunnels. The linings are 48 ft. by 74 ft., and it was originally intended if the rock were sound not to continue the linings into the rock. The shaft-linings were so designed, however, that if the rock were unsound or unreliable, the lining could be continued to the full depth of the shaft, and the upper part built up so as to be above the surface of the ground. In case it should be necessary to continue the lining to the full depth of the shaft, "eyes" were provided through which the shields could be driven, and temporarily stopped with steel plates stiffened with horizontal girders. Each shaft has double walls of steel plates about 5 ft. apart, connected and stiffened by girders, the spaces between the walls being filled with concrete. The shafts on the Manhattan side rest on the surface of the rock, but on the Long Island side it was necessary to sink them into the rock to the full depth, involving the use of compressed-air.

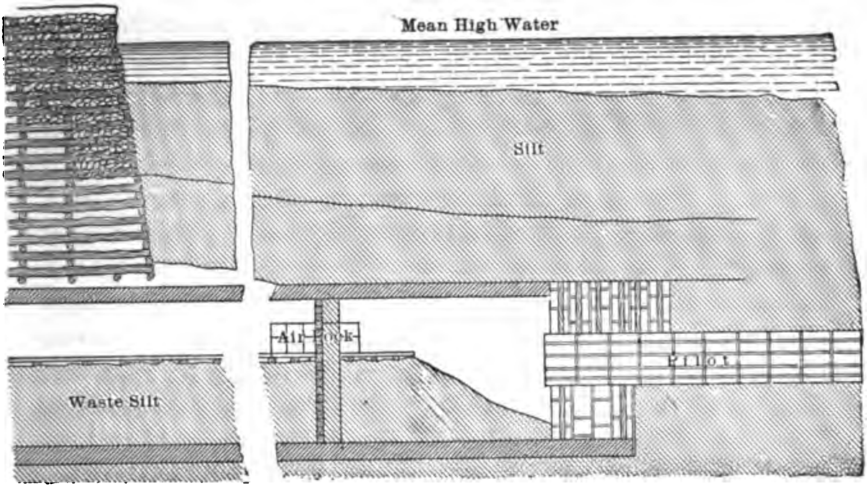
In general, the shafts are shallow, rarely exceeding 100 ft. in depth, and, wherever possible, arranged so that tunneling can be commenced without the necessity of using compressed-air.



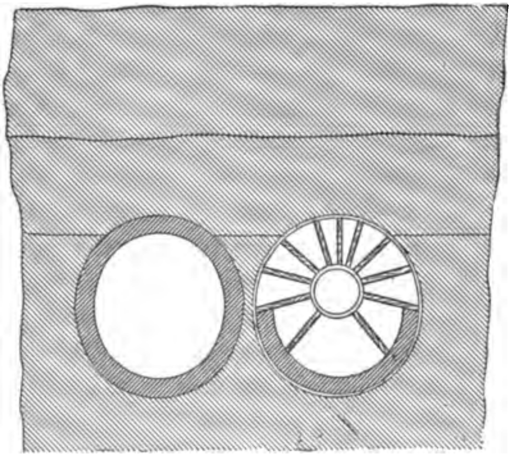


TRANSVERSE SECTION THROUGH CAISSON.

FIG. 2.—THE OLD



LONGITUDINAL SECTION.



TRANSVERSE SECTION.

HUDSON TUNNEL.

Where compressed-air has to be used in starting the heading, caissons are utilized.

Tunneling.—The difficulties of starting the heading from the shaft depend not only on the ground in which the heading will lie, but also on the ground through which the shaft has passed. Even if the heading be started in good ground, there is always the possibility that the sinking of the shaft has so disturbed the ground all the way up that the water and loose material from above may come in when an opening is made. This is what occurred at the commencement of the old Hudson tunnel. In bad ground it is always difficult to make a large vertical opening, and to protect the face at the same time. Moreover, difficulty is encountered in making a good joint between the tunnel and the shaft. In every recent case in and about New York City either the heading has been driven in good rock or the commencement has been safely accomplished under compressed-air, but when the old Hudson tunnel was commenced, several serious accidents occurred in starting the heading and in making the joint between the tunnel and the shaft.

The full-face rock-tunneling work that has been and is being done in New York City is very similar to other rock-tunneling, and it is not necessary to discuss it here further than to mention a new method that has been used for driving the heading. This method is designed for driving under streets, in the neighborhood of heavy buildings and in other places where it is necessary or desirable to reduce the shock caused by blasting to a minimum. It consists of making the first break into the solid rock face by cutting a vertical channel into it and then splitting away slabs of material by exploding vertical lines of holes on each side of the cut. This method would be very attractive, being more scientific and less brutal than firing two vertical rows of converging holes all at once to throw out the wedge-shaped piece of rock between them; but it has been found in practice that the benefits obtained even for driving headings in places where heavy blasting cannot be done, and where it is necessary to reduce shock and vibration, are not sufficiently valuable to offset the loss in time, as the same result may be obtained by increasing the number of holes and by firing relieving cuts.

The soft-ground tunneling in the neighborhood of New York

City is unique in several ways, and a brief description of the difficulties encountered and the methods used to overcome them is of interest.

The bed of the North, or Hudson, river, composed chiefly of a compact silt containing about 33 per cent. by weight of water, flows readily under pressure. It is almost impervious to air and water and is of about the consistency of putty. This material at first presented almost insuperable difficulties to the tunnel-builders, but is now probably the easiest material through which to tunnel. The first successful method used was that of the "pilot" tunnel, illustrated in Fig. 2, which was devised for that work by Mr. J. F. Anderson, one of the original builders of the Hudson tunnel. This tunnel, the interior dimensions of which were 16 ft. wide by 18 ft. high, consisted of a very light wrought-iron shell in segments, lined with about 2 ft. of brick-work. A pilot-tube about 5 ft. 6 in. in diameter was driven from 15 to 20 ft. ahead of the working-face. The tube, made up of wrought-iron plates, was erected one plate at a time, the plate being put in and bolted up as soon as a hole had been excavated to receive it and before the silt closed in again. The thin wrought-iron shell of the large tunnel was erected in the same way, each plate being held in position by a radial strut from the pilot-tunnel. The brick-work was built inside the wrought-iron shell in lengths of 10 ft. at a time. In this way as much as 90 ft. of tunnel has been built in a month. When the work was first taken up by S. Pearson & Son, it was continued by the old methods. It became, however, more and more difficult as the deepest point in the river-bed was approached. The company therefore designed and constructed the shield to complete the work, and initiated methods that have been very successful in tunnels since built. The method of tunneling through soft ground by means of the shield-process had already been successfully used in England, and has been exclusively used in New York. It will be interesting to trace briefly its evolution as far as it has gone on the work in this vicinity.

In general, a shield for soft-ground tunneling is a means of avoiding the poling of the roof and sides of the excavation, and of facilitating and supporting the poling of the face, and forms a cover under which the lining may be erected. It con-

sists essentially of a steel cylinder fitting rather loosely over the outside of the tunnel-lining, under the protection of which the lining can be erected and the face poled if necessary; it must be provided with some means of propulsion, usually hydraulic jacks.

In most cases an inner shorter cylinder is added for stiffness and connected to the outer by radial diaphragms. In the cells thus formed are placed the hydraulic jacks that react against the tunnel-lining and push the shield ahead. When good ground is being tunneled, the space inside the inner cylinder is left open, permitting unrestricted access to the face, except in so far as this is prevented by the vertical partitions usually necessary to stiffen the ring, and the horizontal platforms for the men to work on. If the ground is bad, the face is closed by a diaphragm in which are doors giving access to the face through the "pockets," into which the shield is divided by the vertical and horizontal partitions. When the shield is designed for ground in which it will be necessary to work in front of the shield, to pole the face, for instance, in gravel, or to remove piles, boulders or other obstructions, or to blast out rock, the outer cylinder, known as the "skin," is extended forward further at the top than at the bottom, forming a hood, under the protection of which the men can work, and which also relieves them of the necessity of caring for the roof. If the hood extends for at least two-thirds of the depth (which should always be the case), poling at the sides also is avoided and the only poling to be done is at the face.

The length of the shield depends upon the length of tunnel-lining erected at one time. In the case of cast-iron or steel lining, the "tail," or that part of the skin that can lie behind the lining, is usually made of such length that when the shield is advanced and ready for the erection of a ring, one and a half rings of tunnel-lining are under its cover. The length of the inner cylinder is determined by the length of the jack-cylinders, which is a function of the length of a ring of tunnel-lining. The length of the hood, if one is used, should be about 15 in. greater than the distance that the shield is advanced at a time. This will depend upon the nature of the ground and the length of a ring. In very bad ground, it may not be possible to advance the polings more than a few inches or a foot at a time, but in better ground a full ring-length may be made.

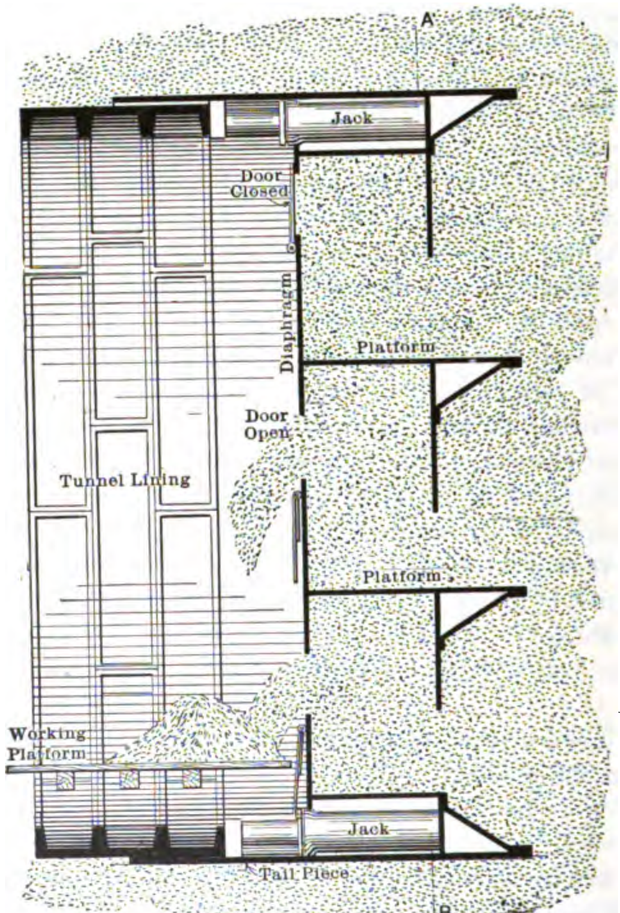
There are certain accessories added to shields, such as erectors, sliding-platforms, face-shutters, etc., that will be described with the shields on which they are used.

The shield designed by Mr. E. W. Moir and used by S. Pearson & Son in the Hudson River north tunnel, shown in Figs. 3 and 4, consisted of a steel shell, or skin, stiffened by an inner shell, and was driven by jacks. The interior was closed by a diaphragm in which were nine hinged doors. The method of working was as follows: Some of the doors of the shield were opened and power turned on to the jacks. The shield moved slowly ahead, laying bare as it went the "tail," which had been lying over the outside of the lining, and ultimately giving, when the jacks were returned, space for the erection of another ring. The silt squeezed slowly in through the open doors and falling upon the platform was loaded into cars and removed. As it moved slowly ahead, the progress of the shield was gauged at various points around the circumference, and when it had traveled the full length of a ring, the doors were closed, the invert cleaned out and the ring erected. This was done by means of a hydraulic erector that trailed behind the shield on rails supported by the iron lining. This erector consisted of an arm revolving on a pivot by two hydraulic jacks, and carrying a third hydraulic jack, the ram of which was fitted with a jaw capable of being attached to one of the tunnel-segments. The whole arrangement was mounted on a carriage with four wheels.

The shield method of tunneling proved much more successful than the pilot-tunnel method, and with it from 7 to 10 ft. per day were built in the Hudson north tunnel.

A modification in the method of working the shield was made when it was found possible later in building the south tube (Hudson tunnel) to push the shield ahead with the doors closed, consequently taking in very little if any silt. This modification reduced the operation of tunneling to two parts: shoving the shield ahead and erecting the iron ring. As much as 50 ft. of tunnel per day was built in this manner. Later, in the Pennsylvania tunnels it was found impossible to control the shield and maintain the line and the grade if the shield were shoved with closed doors, and for good work it was necessary to take in a part of the silt through the doors. If this were not done,

the shield rose above the grade and could not be kept down, and the tunnel itself rose considerably after construction. The amount taken in varied from 20 to 100 per cent. of the volume of the tunnel. The North River silt is so mobile that it would



LONGITUDINAL SECTION.

FIG. 3.—SHIELD FOR CONTINUATION OF OLD HUDSON TUNNEL.

be quite easy to raise or lower a tunnel built in it considerably, and thus change or correct grade and perhaps alignment.

With the methods above described the process of tunneling through a full face of silt has become safe, quick and easy, and it does not appear that much further improvement can be looked

for except in mechanical details—handling muck, shield, rams, and erecting iron—and organization.

When the shield was not entirely in silt, difficulties appeared that necessitated further revision of methods and considerably reduced the rate of tunnel-building. When the north Hudson tunnel had been driven about 4,000 ft. it was found that there was a ridge of rock through which the tunnel would have to

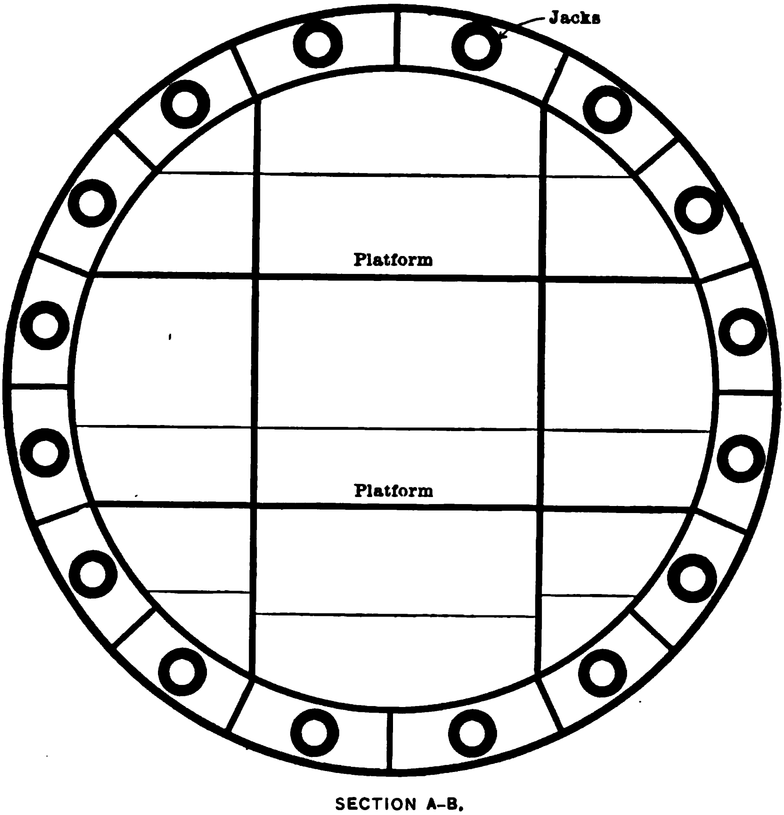


FIG. 4.—SHIELD FOR CONTINUATION OF OLD HUDSON TUNNEL.

be cut, and it turned out subsequently that the rock rose in places as much as 16 ft. above the invert. This was the first time in the history of tunnel-driving that it had been necessary to blast out part of a face of rock, and at the same time prevent an inflow of soft earth. To overcome this difficulty a horizontal platform was built in the shield about 8 ft. above the invert and projecting about 2 ft. in front of the shield, sup-

ported by raking struts from below, to carry the roof of the excavation. Then that portion of the silt between the platform and the surface of the rock was held up by poling-boards strutted to the shield, while the rock in the invert was blasted out with light charges of dynamite.

This method of working was generally satisfactory, and by its use from 2 to 4 ft. of tunnel were built per day. One difficulty that frequently occurred in connection with this work was what is technically called a "blow." The air-pressure in the tunnel, about 35 lb. per sq. in., was found to be satisfactory when ordinary progress was made, any lowering of this pressure allowing the silt to flow excessively. If, for any cause, the shield was kept standing in the same place for a day or two, the silt seemed to soften considerably for some reason or other, with the consequence that when progress was resumed and the shield shoved ahead, the air escaped, usually between the tunnel-lining and the shield-skin, with a loud roar, carrying with it the soft silt, and opening up communication with the river; the pressure in the tunnel fell, the atmosphere became foggy, and unless the escape of air was speedily stopped by stuffing bags of sawdust, clay, or other material into the hole, a point was soon reached when the escape of air began to be accompanied by a heavy inrush of water. This was followed by a rise in the pressure which soon caused another blow, and so on until the tunnel was full of water.

These occurrences were rather alarming and delayed the work considerably, but very seldom, if ever, caused loss of life. They could be and were either prevented, if they seemed imminent, or cured, after the tunnel was flooded, by blanketing the river-bed at the spot where the "blow" occurred. One or two barge-loads of good clay were dumped just over the shield, and this replenished the "cover" that had been or was in danger of being blown away.

Another trouble, and one that was doubtless partly responsible for the occurrence of blows in the Hudson tunnels, was that every time the shield was advanced the face was lost and the silt flowed into the "pockets" of the shield and through the doors. This delayed the work by making it necessary to clean out the pockets of the shield every "shove," and contributed to the production of blows by denuding the tunnel of

just that amount of "covering" clay. This trouble was avoided in the Pennsylvania tunnels by the method of working there adopted. The face above the rock was held by vertical poling-boards, and as these were advanced they were strutted against the shield. When the face was completely poled, horizontal walings were put against the polings and held in place by the sliding-platforms provided, and by struts which passed through the shield against the tunnel-lining. The necessity for supporting the poling independently of the shield was recognized early in the driving of the Blackwall tunnel in London, England, and it has been used in every tunnel of that kind driven in England since. The design and position of the shield (the shield had rolled on its axis about 45°) in the Hudson north tunnel prevented it being used there, but it was used in the Morton street extension and probably in the Hudson south tunnel.

The methods of working described above refer only to tunnels built entirely in silt or part in rock and part in silt, but entirely in ground that is impervious to air and water.

Some portions of the North River tunnels of the Pennsylvania Railroad Co., the Morton street extension of the Hudson tunnel, the Pennsylvania Railroad Co.'s East River tunnels and the tunnels from the Battery to Brooklyn are being built in sand and gravel of various kinds, which permit the escape of air and inflow of water, and must consequently be dealt with in a special manner.

As has already been stated, with a full face of silt, no excavation is done. The shield is simply pushed ahead, and the silt removed is that which flows in through one or several doors. No work is done ahead of the shield.

With a full face of sand or gravel, almost all the material has to be excavated, and very little of it can be displaced, necessitating the maintenance of a vertical face ahead of the shield, either by poling-boards or by other means.

When the face is part silt and part rock, the air-pressure in the tunnel is generally lower than the pressure of the silt, and the poling-boards, etc., are depended upon to exclude the silt. If there is a small leak of silt it does not matter.

When the face is part sand or gravel and part rock, the object aimed at is to make the air-pressure balance the water-pressure; and since the water-pressure is greater at a lower

point of the face than at a higher, it follows that over part of the face the air-pressure is generally too great, and over the remainder too low. The difficulty is to prevent the excessive escape of air on the one hand, and the excessive inflow of ground on the other. In the case of very fine sands, such as occur extensively in the bed of the East river, excessive escape of air is accompanied by the removal of the material; the falling outwards or shrinking of the face, and ultimately by the opening up of a passage to the river, and the occurrence of a "blow." In the case of coarse sands and gravels, this latter difficulty (the removal of material) does not occur, but in this case the ground is so open that the escape of air is always excessive unless a very small portion of the face is exposed at one time. If (in fine sand) the air-pressure were much lower than the water-pressure, it would be impossible to prevent the inflow of the fine sand, which, when saturated with water, is more mobile than the silt, and the polings would collapse.

It is evident that the adjustment of the air-pressure in a tunnel passing through sand or gravel is much more delicate and difficult than in a tunnel passing through silt.

With regard to methods in the Morton street extension, and in those parts of the Pennsylvania tunnels that are in sand and gravel, the method of working was similar to that described for a face part silt and part rock, except that horizontal polings were used instead of vertical polings. The top board was advanced first and strutted to the shield, and then the second, and so on until the whole face was advanced, when "soldiers" were put against it and held by the sliding-platforms and by struts that passed through the shield to the tunnel-lining.

In the East River tunnels of the Pennsylvania Railroad Co. steel shutters were provided to be used instead of poling-boards. These shutters consisted of steel plates stiffened with angles and provided with small doors, running in guides, which were attached to the compartment walls of the shield. They were controlled by long screws fixed to their ends and running through bearings attached to the compartment-walls. The top shutter was intended to be advanced first, the material being raked out through small doors. Then the second one could be advanced, the material being removed through the space between the top one and the second one, and so on. This is the

way in which a similar shield was used for the Blackwall tunnel, with excellent results.

In the East River work, the shutters have not, so far, been used in this way, but the face is poled with horizontal poling-boards down to the level of the lower platform, the lower part of the shield being left practically full of sand. These polings are then held up with struts that will telescope under considerable pressure while the shield is advanced.

This is, in effect, the same method that was used in the North River tunnels.

To sum up, it is evident that the method used of working a sand- or gravel-face consists of poling the face with horizontal polings, and then holding it independently while the shield is advanced. An attempt was made to use vertical polings in the North River tunnels, but was abandoned. The method thus used was probably originally used in part of the Blackwall tunnel work, and with modifications was used in coarse gravel in the Baker street and Waterloo tunnels. It appears to be the best, if not the only satisfactory method of working with a face of sand or gravel.

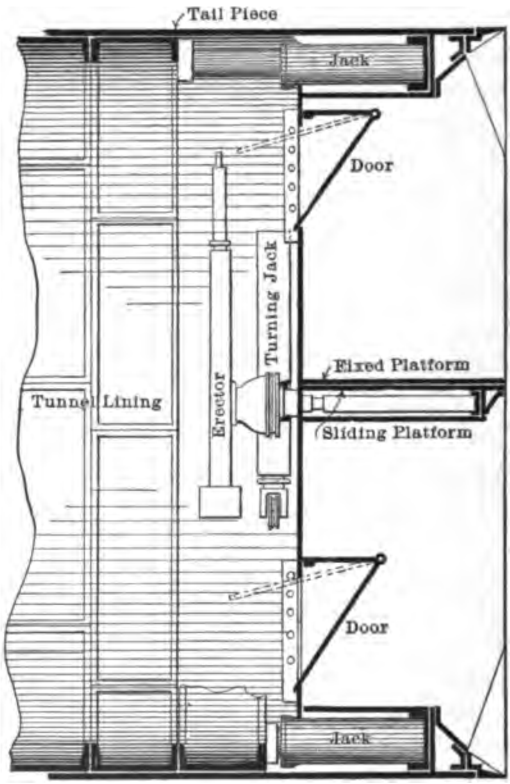
At this point a brief description of the various types of shields that are being used may be of interest.

The shield for the north tunnel of the New York & Jersey Railroad Co. has been mentioned. It consisted of a steel shell or skin, 19 ft. 11 in. in exterior diameter, 10 ft. 6 in. long and 1.25 in. thick, stiffened by the addition of an inner shell, 3 ft. 2 in. long and 16 ft. 11 in. in internal diameter, connected to it by radial webs. The compartments of this ring were utilized to hold the 16 hydraulic jacks used to propel the shield, utilizing the iron lining as an abutment. The interior, shut off from the tunnel by a diaphragm, was divided into nine pockets by two vertical partitions and two horizontal platforms, and these pockets were open to the face and accessible from the tunnel through hinged doors.

The south tunnel shield, Figs. 5 and 6, consisted of an outer skin, 16 ft. 9 in. in internal diameter and 10 ft. long, with an inner shell of 14 ft. 9 in. internal diameter and 3 ft. long. The space inside this shell was divided into six compartments, or pockets, by two vertical stiffening partitions and one horizontal platform. The face was closed with a diaphragm, which was

provided with six doors that swung inwards on a pivot. A horizontal sliding-platform in three parts was provided, each part being actuated by two hydraulic jacks.

The erector used for placing the lining in position, which was on the shield, consisted of a long arm carrying a hydraulic jack, which was caused to rotate about an axis coincident with the axis of the shield by two other hydraulic cylinders. The



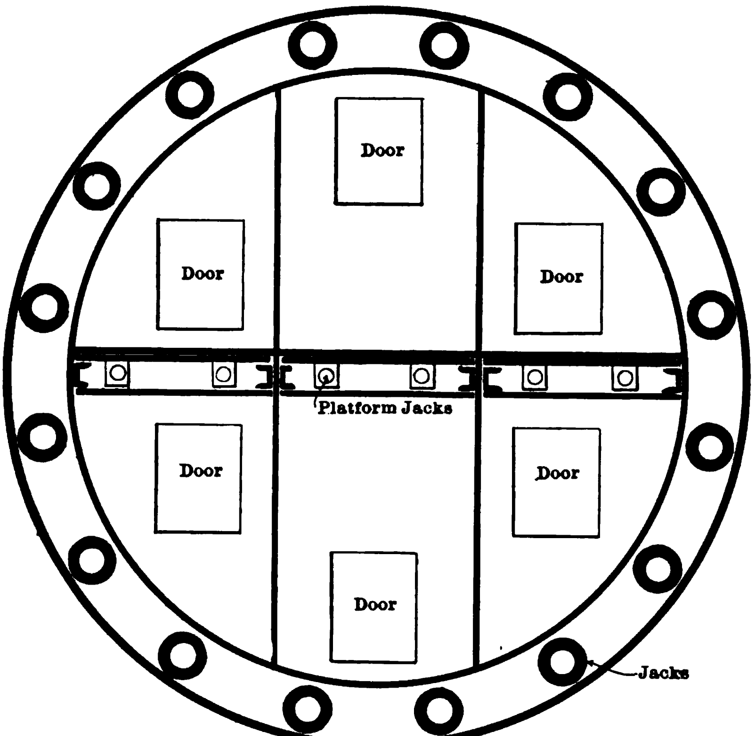
LONGITUDINAL SECTION.

FIG. 5.—SHIELD FOR HUDSON RIVER SOUTH TUNNEL.

shield was driven by 16 hydraulic jacks, 8 in. in diameter, suitable for use with a pressure of 5,000 lb. per sq. in., giving a maximum pressure of 125 tons per jack, or 2,000 tons for the whole shield.

The shields that were used for the North River tunnels of the Pennsylvania Co., Figs. 7 and 8, had an external diameter of 23 ft. 6¼ in.; the skin being made up of two 0.75- and one ⅝-in.

plates, the internal diameter was 23 ft. 2 in., allowing a clearance of 1 in. all around the 23 ft. tunnel-lining. The total length of the shield was 15 ft. 11.5 in., and the hood, which covered rather more than one-third of the circumference, extended 2 ft. 3⅝ in. further. The length of the tail was 6 ft. 4.5 in., being long enough to cover two and a half rings of the lining 30 in. long. The forward part of the shield was divided into nine pockets



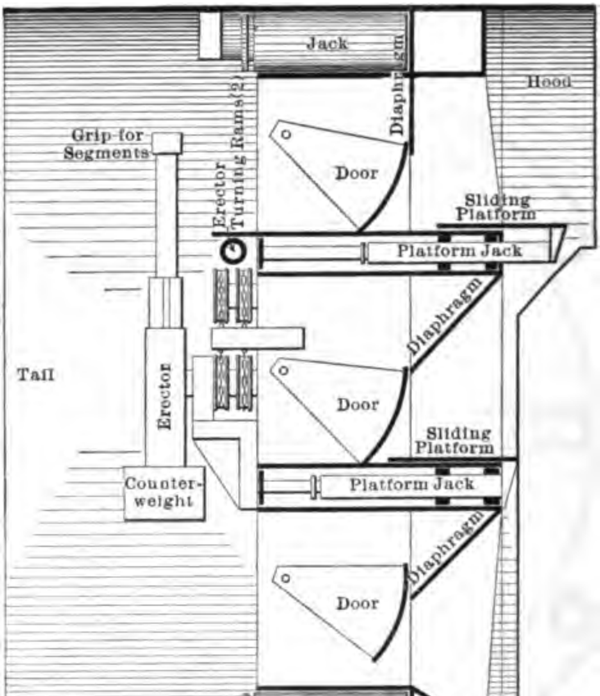
TRANSVERSE SECTION.

FIG. 6.—SHIELD FOR HUDSON RIVER SOUTH TUNNEL.

by two vertical partitions and two horizontal platforms. Each of the platforms had a sliding extension made in four pieces, each piece being actuated by two hydraulic jacks.

The pockets were closed at the end nearest the face by plates covering about half the opening and inclined so that the upper edge of the plate was nearest the face. The remainder of the opening could be closed by means of a door. The doors were segments of a cylinder, and swung in pivots attached to

the vertical diaphragms. A single erector was used, which being typical of the erectors used on the shields described, is shown in Fig. 9. The shield was driven by 24 jacks, with rams of 8.5 in. diameter. The maximum hydraulic pressure available was 5,000 lb. per sq. in., and this gave, with all jacks, a total forward pressure of 3,300 tons.

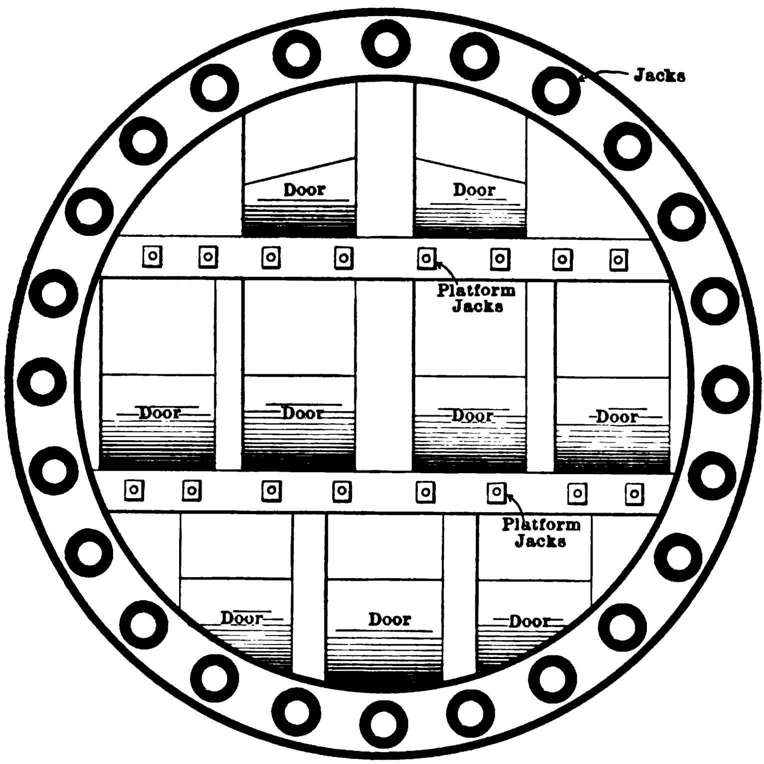


LONGITUDINAL SECTION.

FIG. 7.—SHIELD FOR NORTH RIVER TUNNELS, PENNSYLVANIA RAILROAD.

The East River (Pennsylvania tunnels) shield, of which the leading features are shown in Figs. 10, 11, 12 and 13, is of very similar design to the one used for the Blackwall tunnel. It is 18 ft. long over all, and is provided with a hood that can be advanced and withdrawn at will. The face is closed by two diaphragms fitted with air-locks, the object being to permit of a higher pressure of air being used in the face than in the tunnel.

The shield is fitted with two erectors, and the erection of the iron lining can go on at both sides of the tunnel at the same time. The erector-arm in this case is revolved by a single cylinder, the ram being fitted with a rack which gears with the toothed hub, by which the revolving arm is mounted on its pivot. In the erectors on other shields mentioned there were two cylinders for turning the arm, and the transmission was



TRANSVERSE SECTION.

FIG. 8.—SHIELD FOR NORTH RIVER TUNNELS, PENNSYLVANIA RAILROAD.

either by cable or by chain. The face-shutters with which this shield is fitted have already been briefly described. There are 27 jacks, with 9-in. diameter plungers, for shoving the shield, and they are capable of exerting a total forward pressure of 4,050 tons with 5,000 lb. per sq. in. pressure. They are more closely spaced in the bottom than in the top. The reason for this arrangement has already been suggested; if the air-pres-

sure were so regulated as to balance the water-pressure at the bottom of the shield, it would be about 10 lb. per sq. in. in excess at the top, and "blows" would result; if it be less than sufficient, as is the case, the invert of the shield and tunnel is filled to a corresponding level with sand and water, and below this level the face cannot be poled. Additional power is there-

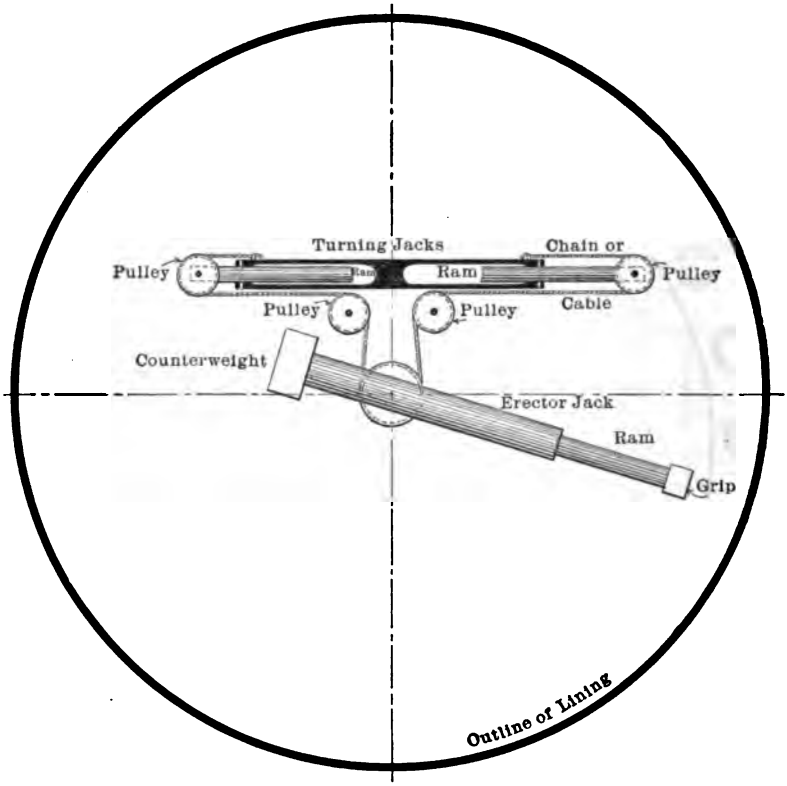


FIG. 9.—ERECTOR FOR IRON LINING.

fore necessary to displace this material in the bottom when the shield is advanced.

A cross-section of iron lining used on the Pennsylvania tunnels is shown on Fig. 14 as a type.

The shields, Figs. 15 and 16, that have been used in the Battery tunnel of the Rapid Transit Commission differ from others in several respects, the most important of which is, probably, the lack of provision for vertical protection of the face. The shield was provided with a fixed horizontal platform, and arrangements

were made for other horizontal platforms to be made of poling-boards, and on these the material was allowed to fall with its natural slope. The erector was mounted on a separate carriage that trailed along behind the shield. It was rotated by a small three-cylinder compressed-air motor, and the hydraulic cylinder in the arm received power, as did the shield-jacks, from a compressed-air-driven power-pump mounted on the same carriage.

The cost and the rate of driving tunnels through loose ground by the shield-method vary very considerably, and are dependent upon a number of considerations. Of course, the most important is the nature of the ground. In a soft clay or silt, where it is sometimes possible to shove the shield ahead without removing through the tunnel any material whatever, the labor-charges are very low.

In a sand or gravel fully charged with water where all the material has to be removed, and the face kept by polings, and especially where part of the face is rock, the cost is much higher. A higher air-pressure has to be maintained, with consequent increase in the price of labor. The labor is not so efficient, the progress is very much less, and often it is quite irregular. For instance, in the Hudson tunnel at one time there were two faces at which work was proceeding, one of sand and the other of silt. The shields were alike and the tunnels the same size. The progress in the first was at one time not much more than 1 ft. per day, although this was afterwards increased to 6 or 7 ft. per day. In the second, the progress was at the rate of 50 ft. in 24 hours.

The cost of labor per day was probably about the same in each case, so that the labor-cost per unit of strength was evidently very different in the two cases.

The design of the shield is another matter that has very great influence on the progress made. Of necessity, every shield that has been used up to the present time has been more or less experimental, and many of them have had to be changed or added to in some respect or other during the course of the work. There seems to be no reason, however, with the lessons that have been learned under the North and East rivers, together with the experience that has been obtained before, why

a shield should not be designed that would be suitable for any conditions that might arise during the progress of the work.

Such a shield would have a hood extending down over about two-thirds of the circumference, and forward about 4 ft. from the cutting-edge. It would have strong and efficient sliding-platforms. It would be provided with some means of support-

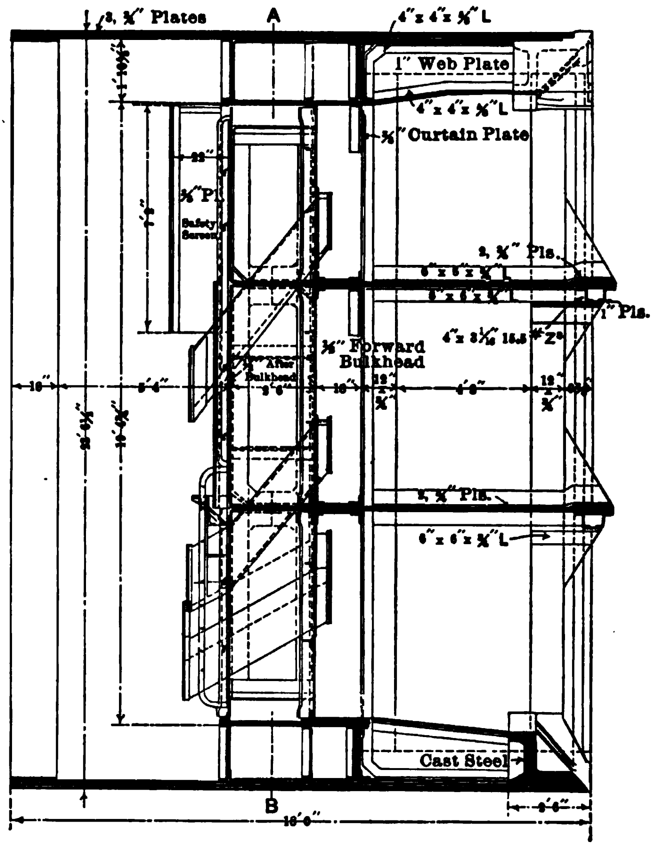
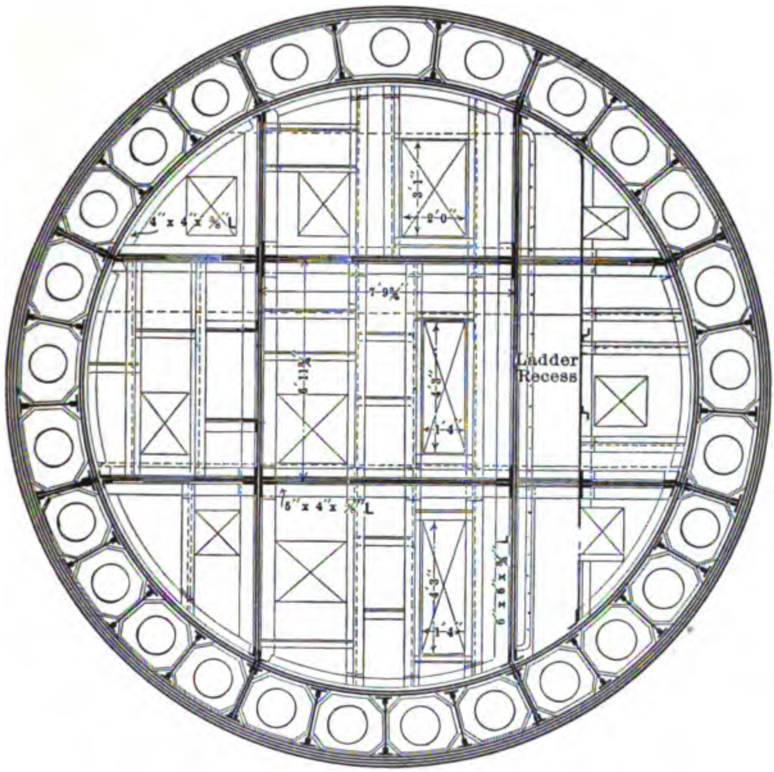


FIG. 10.—SHIELD FOR EAST RIVER TUNNELS, PENNSYLVANIA RAILROAD.

ing the face, so that the shield could be advanced without any change in the arrangement of the supporting-pressure. The door-space would be as large as could be obtained, and the openings would be fitted with doors that could be kept open or closed, as was required by the method of working and the nature of the material, and that were capable of being surely and quickly closed in an emergency. All the openings would be

fitted with a removable siphon-trap arrangement for the protection of the men and tunnel in the event of a blow in the face. As regards the propelling-mechanism, the jacks should be provided with a good automatic "pull-back" that would avert the troublesome necessity of prying and wedging back the rams in order to erect the iron.

The labor question is one that has probably a greater effect



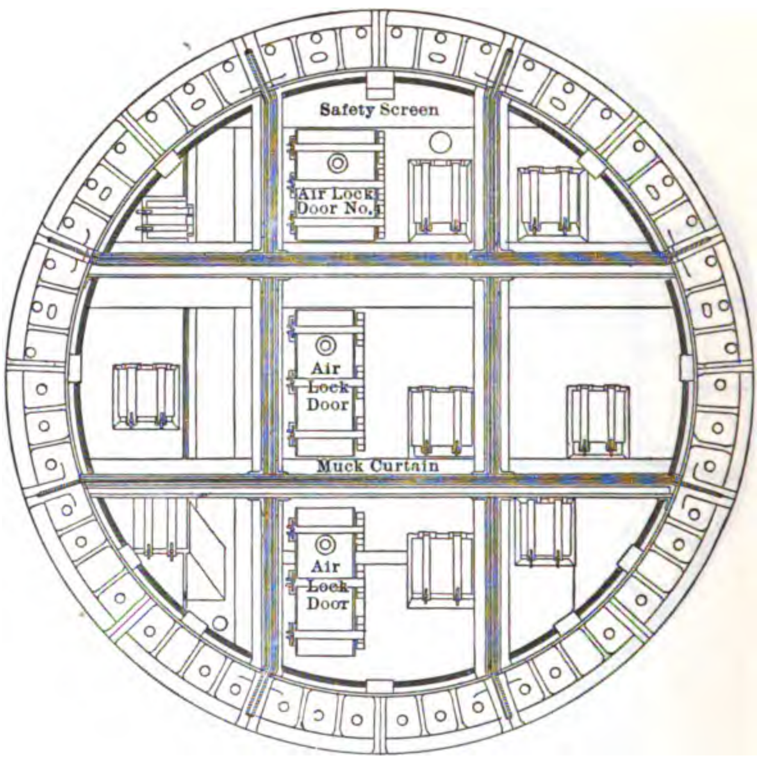
SECTION A-B.

FIG. 11.—SHIELD FOR EAST RIVER TUNNELS, PENNSYLVANIA RAILROAD.

on the cost of tunneling than is the case in other kinds of engineering work. The progress of a tunnel is peculiarly liable to interference caused by unskillful or unsympathetic work in the face. It has been necessary in every tunnel that has been built in New York to train the men in their work, and to produce from the rawest material more or less skilled tunnelbuilders. This has increased considerably the cost of supervision, and has added materially to the natural difficulties of

the work. The task has not been at all simplified by the tendency to "unionize" the laborers and foremen, nor by the tendency of the sensational newspapers to magnify the "heroism" of the men.

The depth of the tunnel below the surface, in addition to increasing the cost of raising and lowering material, usually affects the air-pressure it is necessary to use. An increase in the air-



FRONT VIEW.

FIG. 12.—SHIELD FOR EAST RIVER TUNNELS, PENNSYLVANIA RAILROAD.

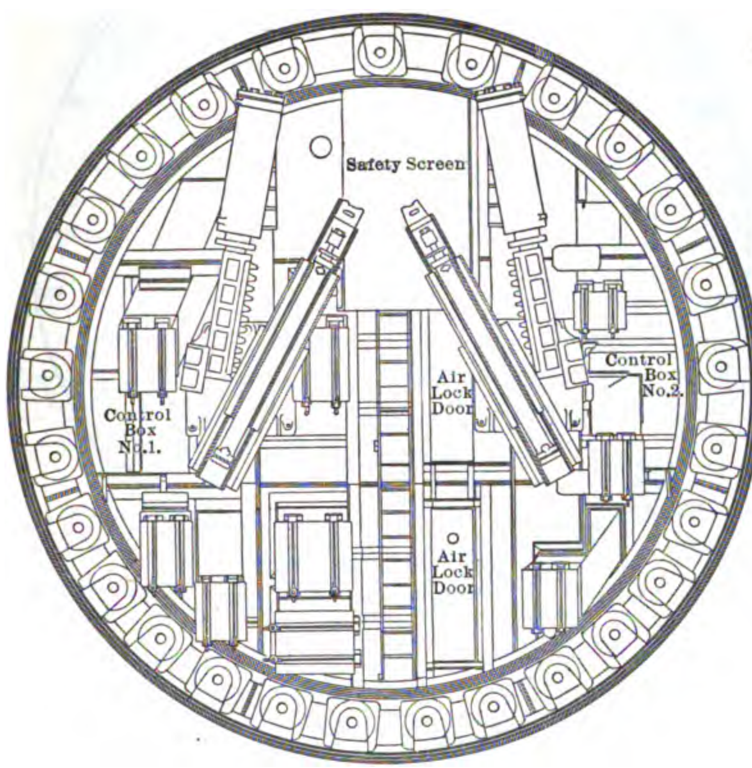
pressure is accompanied by an increase in the daily rate of pay and by a diminution of the number of hours worked, and, since the work proceeds night and day, by an increase in the number of men employed.

The size of the tunnel has its effect on the efficiency of the work, but it is not possible here to make a full discussion of this point. It may perhaps be proper, however, to emphasize the somewhat obvious fact that the work will be more efficient

in a tunnel where it is possible to work a great number of men in the face, conveniently, at one time.

The following figures, showing the approximate rates of progress attained in the various tunnels named, may be of interest:

Hudson River North Tunnel (Old Hudson Tunnel): a brick tunnel in silt, 16 ft. wide by 17 ft. high internally, driven by



REAR VIEW.

FIG. 13.—SHIELD FOR EAST RIVER TUNNELS, PENNSYLVANIA RAILROAD.

pilot-tunnel method at the rate of about 3 ft. per day. Iron-lined shield-driven continuation of above tunnel, 19 ft. 6 in. external diameter, in silt, at the rate (exclusive of contingencies) of from 10 to 12 ft. per day; in part rock and part silt, from 1 ft. 8 in. to 3 ft. 4 in. per day. From 18 to 20 men at work at the shield.

Hudson River South Tunnel (16 ft. 7 in. external diameter): an iron-lined shield-driven tunnel constructed through silt at

the rate (exclusive of contingencies and delays for the lack of iron lining) of about 50 ft. per day.

Morton street extension of Hudson Tunnel: 16 ft. 7 in. ex-

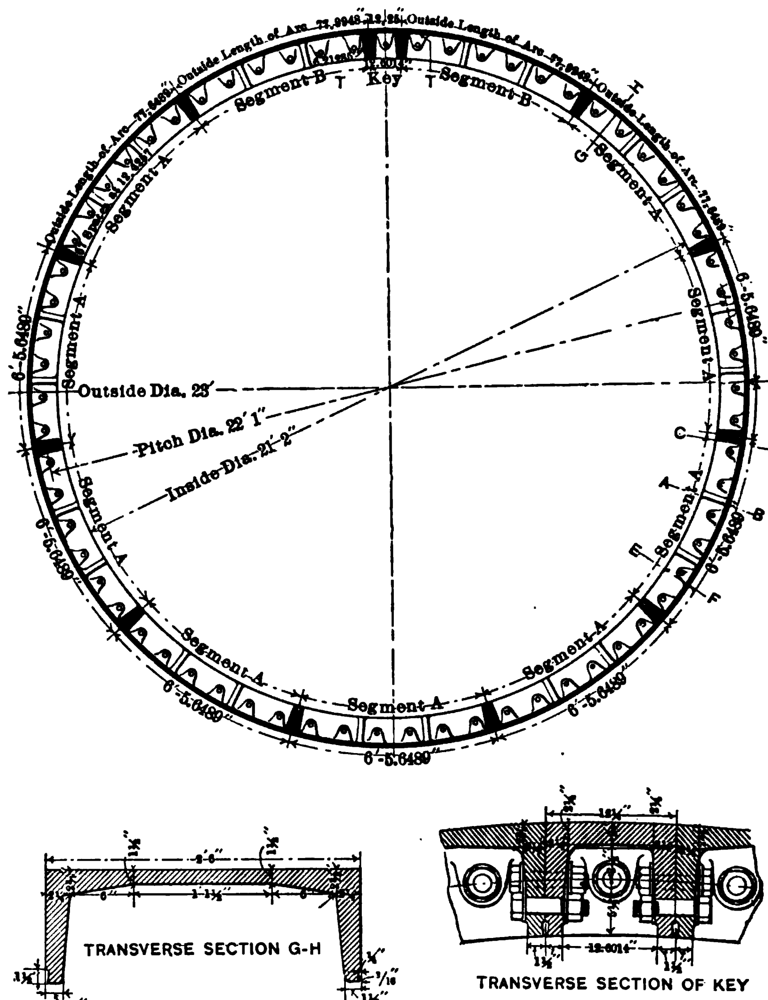


FIG. 14.—TYPE-SECTION OF IRON LINING.

ternal diameter, in sand, driven at the rate of from 1 to 8 ft. per day. From 18 to 20 men at the shield.

Pennsylvania North River Tunnels: 23 ft. external diameter, in rock, or face of part rock and part silt, from 2 to 3 ft. per day average; full face of silt under river, from 13 to 14 ft. per day average. About 30 men at the shield.

The Pennsylvania East River tunnels are still being driven. They are 23 ft. external diameter, and the progress has varied from a few inches to 12 ft. per day, according to the nature of the ground passed through.

Battery Tunnel of Rapid Transit Commission: 16.7 ft. external diameter, in sand, made maximum progress of 12 ft. per day. About 10 men at the shield.

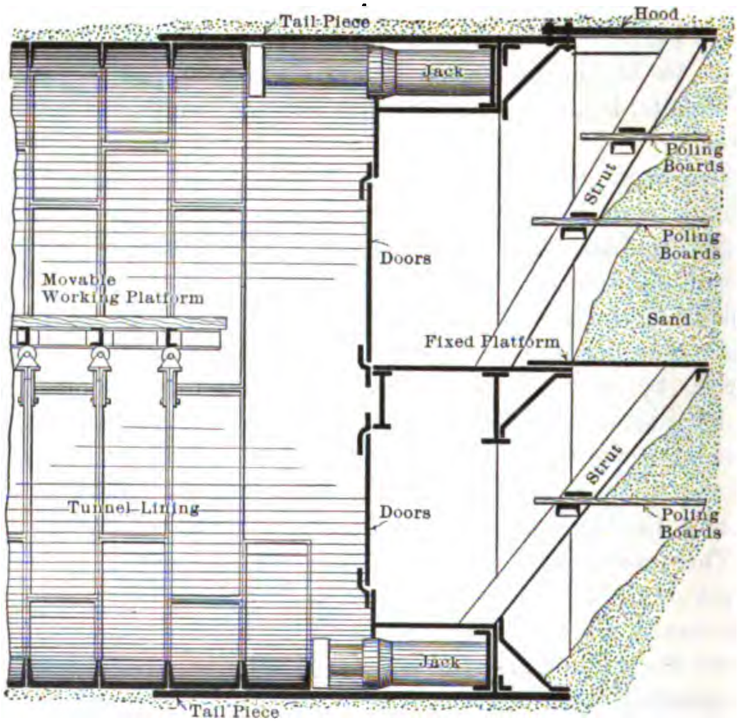
The rate of pay for tunnel-laborers in compressed-air is from $3 to $4 per day of from 8 hr. in pressures below 32 lb. to 6 hr. in higher pressures. These figures are, of course, approximate, being dependent upon varying conditions encountered.

The work here described is distinguished from ordinary mining work by the fact that it is carried on with the aid of compressed-air, which assists to prevent the inflow of the fluid or semi-fluid earth. A bulkhead is built in the tunnel or shaft, separating the face of the work from the outside air and forming a chamber into which air is pumped at the necessary pressure. Access to this chamber is obtained through air-locks, which are usually steel cylinders fitted with air-tight doors opening towards the face and with pipes and valves, by means of which the pressure inside the locks can be varied at will from normal pressure to the pressure inside the chamber.

The pressure inside the chamber is dependent upon the depth of the tunnel below the surface of the ground, being in the case of silt equal to or less than the head of silt and water above the tunnel, and in the case of sand or gravel equal to the head of water a few feet above the invert of the tunnel.

The quantity of air necessary, and consequently the capacity of the compressor-plant, depends, in the case of a tunnel in silt or other air-tight material, upon the number of men working in the tunnel, the object being to give efficient ventilation everywhere, and to maintain the air of such purity that analyses do not show the presence of more than 0.1 per cent. of carbon dioxide. This may take as much as 100 cu. ft. of free air per man per minute. In the case of sand, gravel, or other open ground, sufficient air is required to replace that which escapes through the face, and the amount depends upon the closeness of the ground and the manner in which the face is worked.

The effect of compressed-air on the health of the men is a matter for doctors rather than engineers; experience has shown that work can be carried out without risk to life or injury to health in pressures up to 35 lb. per sq. in., provided certain precautions are taken. These are: (*a*), the exclusion of men not in good physical condition, especially when suffering from heart or lung troubles or catarrhal affection of the head; (*b*),



LONGITUDINAL SECTION.

FIG. 15.—SHIELD FOR BATTERY TUNNEL.

efficient ventilation of the tunnel, particularly where men are at work; (*c*), provision of warm clothing and warm quarters for the men on leaving the tunnel, and, in general, the avoidance of chills; (*d*), the careful observance by the men of all the ordinary rules of health.

There is one method of tunneling that has been tried experimentally, and is worthy of mention—viz., the "freezing" process. This process, which has been successfully used many times

in shaft-sinking, has never been applied to driving a long tunnel. It was used successfully in passing through a short length of bad ground in the Stockholm tunnel, and is now being tried in a tunnel in Paris. The problem of tunneling by freezing is essentially different from shaft-sinking by freezing. The face is vertical instead of horizontal, and the length is great and in-

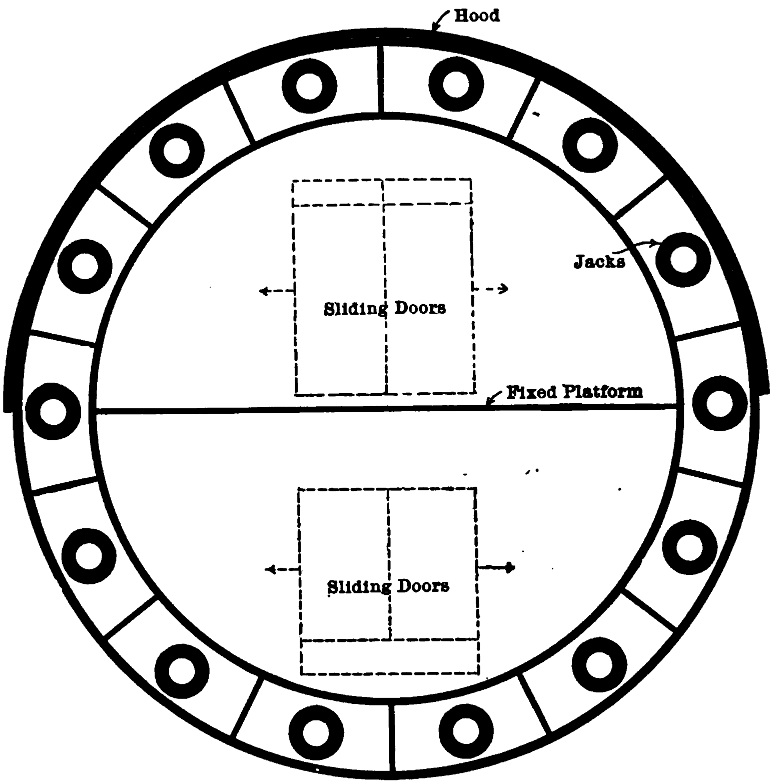


FIG. 16.—SHIELD FOR BATTERY TUNNEL.

definite. In the case of a shaft the freezing-pipes can be sunk outside the excavation and all efforts concentrated in freezing an impervious wall about the ground to be excavated. In the case of a tunnel, it is almost unavoidable that the freezing should take place from the center, and in consequence the ground that is frozen the hardest and is strongest is the ground that has to be excavated, and would perhaps have been better

if soft. The weakest part of the frozen mass is the wall outside the excavation—the part where strength is most necessary.

Among the contractors' proposals to construct the East River tunnels of the Pennsylvania Railroad Co. was one to drive them by the freezing-process, and the method suggested was first to drive a small pilot-tunnel by any ordinary method, and then from that to freeze the ground out to such a distance that when the larger tunnel was excavated a sufficient thickness of frozen material would remain to resist the pressures of the water and the unfrozen ground beyond. The Pennsylvania Railroad Co. thereupon, with characteristic enterprise and forethought, made an experiment in tunneling by the freezing-process at considerable cost.

A shaft was sunk to a depth of about 85 ft. through the East 35th street pier, and a tunnel 7 ft. 6 in. in diameter was driven out a distance of 165 ft. by means of a small shield and compressed-air. A number of pipes were attached to this lining with their axis parallel to the axis of the tunnel, and brine at a temperature of about 35° below zero, Fahrenheit, was circulated through them for several months. Careful observations were made of the temperature of the ground surrounding the pilot-tunnel and of the quantities of heat extracted by the brine, and laboratory determinations on a large scale were made of the thermal conductivities of different kinds of sand and gravel. The object of the experiment was not merely to test the feasibility of constructing a large tunnel by the freezing-process, but to collect, in addition, such information as would enable reliable estimates to be made of time and cost of driving tunnels of various diameters in different kinds of water-bearing ground by the freezing-process. The information that has been obtained is very complete, and as general in nature as it could be made.

After carefully watching this test, and studying the results obtained, I am of the opinion that freezing may be made a very valuable auxiliary to tunneling in water-bearing sands and gravels. It will not, as expected by some, supersede the shield and compressed-air methods, nor will it, in all cases, avert the necessity for the use of compressed-air; but it will, if intelligently applied, eliminate many of the uncertainties and diffi-

Fig. 17.—View of Brine-Pipes in Pilot-Tunnel.

FIG. 18—VIEW OF PILOT-TUNNEL DURING REFRIGERATION.

culties of the methods now in use. Figs. 17 and 18 are views of the pilot-tunnel during the test.

Tunnels in Construction (Fig. 1).—New York & Jersey Railroad Co.'s tunnels: Of the tunnels at present under construction, the first to be commenced was the old Hudson tunnel. This work was commenced in 1879 by D. C. Haskin, who sunk a shaft at the foot of Fifteenth street, Jersey City, and drove about 1,542 ft. of the north tunnel and 600 ft. of the south tunnel, chiefly by the pilot-tunnel method above described. A shaft was also sunk on West street, at the foot of Morton street, on the New York side, and a short length of the north tunnel was driven towards the Jersey shore. In 1882 the work was temporarily abandoned, to be taken up again in 1890 by S. Pearson & Son, who continued work in the north tunnel from Jersey City by the same method that Haskin used until perhaps 100 ft. had been driven. A shield was then built and an iron-lined tunnel constructed of 1,900 ft. in length, making the total length of the tunnel about 4,000 ft. by August, 1891. At this time, the funds being exhausted, the work was abandoned.

The undertaking was resumed by the New York & Jersey Railroad Co., with Mr. William McAdoo as President and Mr. Chas. M. Jacobs as Chief Engineer, in 1901, and now forms part of an extensive system. This consists of twin tunnels from the station of the Delaware, Lackawanna & Western Railroad Co. in Hoboken, past the Erie Railroad station and the Pennsylvania Railroad station to the Jersey City terminal of the Central Railroad of New Jersey. These tunnels are connected with the New York side by the Hudson & Manhattan Railroad twin tunnels running from the Pennsylvania Railroad terminal to Cortlandt street, where a large terminal is being built; and by the twin tunnels (the original Hudson tunnel) running from the foot of Fifteenth street, Jersey City, to the foot of Morton street, and thence up Sixth avenue to 33d street, where a terminal will be built. The total length of single track tunnel in this system is about 12 miles.

The tunnels of the Pennsylvania Railroad Co. were commenced during the administration of the late A. J. Cassatt, with Mr. Samuel Rea in charge, and are being constructed un-

der the general supervision of a Board of Engineers appointed by the late Mr. Cassatt, with General Raymond as Chairman, and with Mr. Alfred Noble and Mr. Charles M. Jacobs as Chief Engineers of the East and North River divisions, respectively. There are two tunnels, 25 ft. 10 in. wide and 21 ft. 5 in. high, which start from the portal at the west side of Bergen Hill on the Hackensack meadows through the hill to a point 224 ft. east of the Weehawken shaft. For the most part these tunnels are in trap rock and driven by ordinary methods, but the contact of the trap and the sandstone occurring in the shaft at Weehawken, the rock just east of the Weehawken shaft is mixed in character. From the shield-chambers, 224 ft. east of the Weehawken shaft, the tunnel is first in rock, then in rock overlain by sand and gravel, then sand and gravel, and then silt, which extends across the whole width of the river. The tunnels were driven by shield and compressed-air methods, as described before. While passing through the sand and gravel it was found necessary to drive one tunnel at a time, the other being used to drain the ground somewhat. On the New York side the rock-level rises again, and the tunnel, from being entirely in silt, is entirely in rock, and the iron-lined tunnels end at a point about 1,070 ft. east of the bulkhead. Where the iron-lined tunnel was entirely in rock, it was driven ahead of the shield, and a concrete cradle laid to receive the iron lining which was erected behind the shield as it advanced.

From the shield-chamber to the east are twin tunnels that extend to the terminal station, which pass through rock varying in character from mica schist to hard trap, and overlain by sand and gravel. Where wholly in rock with good rock-cover, these tunnels are being excavated by ordinary rock-tunneling methods; where partly in rock and partly in gravel, they are excavated by cut-and-cover methods. From the terminal station eastward run two three-track tunnels, one under 32d and one under 33d street. Just west of Fifth avenue the construction is changed to two pairs of single-track tunnels, which run into the shafts near First avenue. These tunnels are chiefly in rock; but there are short lengths where the rock cover is very thin, and in places it runs out altogether and there is part of a face of sand and gravel. The construction is again

changed at the shafts near First avenue, where four iron-lined river-tunnels start and pass through rock, rock and sand and gravel, into a full face of quicksand, thence through a reef of rock into sand again, then back into rock and through the river-shaft in Long Island City for about 2,000 ft. to East avenue. From East avenue to Thompson avenue the work is either cut-and-cover or open cut. The total length of single tunnel in this system is about 18 miles.

With reference to the material through which these tunnels have been or are being driven, the prevailing materials forming the beds of the North and East rivers, while apparently quite different, have one or two points of striking similarity. They are composed of extremely fine particles, and both in their natural states contain surprisingly large percentages of water.

The silt of the North river resembles a soft clay, and contains at the level of the tunnels about 33 per cent. by weight of water, which is considerably more than sufficient to fill the voids, if the particles were spheres. It is almost impervious to air and water, and flows freely under pressure. It apparently will not stand at any angle.

The chief material found in the East river is an extremely fine red sand, divided by occasional horizontal streaks of stiff red clay. It contains about 22 per cent. by weight of water and is a typical quicksand. Under the action of a sufficient pressure of compressed-air, the water is expelled from it and it will stand vertically or even overhanging, and when in this condition it resembles a rotten sandstone. It permits the escape of compressed-air, though not at first freely, and when the pressure of air falls below the balancing-pressure it becomes quite liquid.

At one time it was thought that the tunnels under the North river would have to be supported against downward displacement, which it was supposed the vibrations caused by traffic might cause. A very careful investigation of the whole matter was made by General Raymond, who studied all the reliable evidence obtainable from the old Hudson tunnel and from the Pennsylvania tunnels, and made a long series of observations of the pressure exerted on the tunnels in both cases by the silt by means of a specially constructed pressure-gauge. He points out that, provided it be made tight against water

and silt, it is not possible for a tunnel that is lighter than the displaced material to settle, and that the tunnels of the Pennsylvania Co., which, while normally lighter than the silt, may, when a train passes through, be momentarily heavier, will have to be held against both upward and downward motion, in order that they might be perfectly safe under all conditions, and that the only effect, if any, of vibrations, will be to tend to cause the tunnel to move in the direction of the resultant of the pressures, which, in general, is upwards.

The tunnels of the Rapid Transit Commission, now under construction, consist of iron-lined twin tunnels in continuation of the Subway, from the Battery under the river to Joralemon street, Brooklyn, thence to a connection with the Fulton street line, Brooklyn. The ground passed through, on the Manhattan side, was rock of a variable kind, some hard, and some soft and decomposed with irregularities and fissures; the roof of the excavation was timbered, and the iron lining was erected by means of an erector that traveled on rollers attached to the lining, the space between the rock and the lining being packed with dry rock and grouted; from this rock the tunnel ran into sand and gravel and then again into rock; on the Brooklyn side the work was entirely in sand and gravel and carried on entirely with shields.

The tunnels of the New York & Long Island Railroad Co. are twin iron-lined tunnels of about 15 ft. 3 in. diameter driven in rock from 42d street to Man-o-war's Reef and thence partly in sand to Long Island City. From New York to Man-o-war's Reef it was expected to avoid compressed-air work, as the tunnel is entirely in rock, but fissures occur in the rock and compressed-air has been used to some extent.

All the tunnels above mentioned are under construction at present, and make a total of 38 miles of underground workings.

In addition to these works under construction it may be mentioned that about 66 miles of new subways are projected, and most of them must be constructed in the near future.

As regards the illustrations of this paper, I am grateful for permission to reproduce Fig. 2 from a paper by Mr. William Sooysmith entitled the Hudson River Tunnel,[1] and Figs. 10,

[1] *Transactions of the American Society of Civil Engineers*, vol. xi., pp. 314 to 323 (1882).

11, 12 and 13 from the working-drawings of Messrs. S. Pearson & Son, contractors for the East River tunnels of the Pennsylvania Railroad Co., and the photographs from the collection of the Pennsylvania, New York and Long Island Railroad Co.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Formation and Enrichment of Ore-Bearing Veins.

BY GEORGE J. BANCROFT, DENVER, COLO.

(New York Meeting, April, 1907.)

INTRODUCTION.

IT is unnecessary to repeat here the contents of many valuable contributions to this subject which have appeared in the *Transactions* and in the publications of the U. S. Geological Survey. As a basis for the further suggestions of this paper, the following are the most important:

1. The investigation of J. R. Don,[1] showing the gold of certain Australasian veins to have been deposited by ascending solutions, and not by lateral secretion.

2. The theory of Prof. Posepny,[2] distinguishing the vadose from the deep circulation, and ascribing the origin of certain classes of ore-deposits to ascending solutions of the latter class.

3. The theory of Prof. Van Hise,[3] as to the underground circulation and the primary enrichment of veins thereby.

4. The paper of Prof. J. F. Kemp,[4] showing that ore-deposits are largely the products of "expiring vulcanism." Many of Prof. Kemp's ideas have been widely adopted by mining men.

5. The theory of secondary enrichment, so lucidly expounded by Mr. S. F. Emmons.[5] This theory, dealing with the rearrangement of ore-bodies after primary mineralization, has been generally adopted, and seems to me to have been as completely proved as the nature of the case permits.

There are two facts which I think should be constantly borne in mind in formulating a theory of the genesis of ore-

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[1] The Genesis of Certain Auriferous Lodes, *Trans.*, xxvii., 621 (1897).

[2] *Genesis of Ore-Deposits*, pp. 1 to 187, and *Trans.*, xxiii., 197 to 369 (1893).

[3] Some Principles Controlling the Deposition of Ores. *Genesis of Ore-Deposits*, pp. 282 to 432; also, *Trans.*, xxx., 27 to 177 (1900).

[4] The Rôle of the Igneous Rocks in the Formation of Veins. *Genesis of Ore-Deposits*, pp. 681 to 709; also, *Trans.*, xxxi., 169 to 198 (1901).

[5] *Genesis of Ore-Deposits*, p. 462, and *Trans.*, xxx., 206 (1900).

bodies. The first is that commercially valuable mines are relatively few. Countless veins present all the characteristics of good mines, except the values. I suppose that there are a hundred barren veins for every enriched one, and even the latter are rarely enriched to the extent of more than 20 per cent. of their volume. The stope-map of any old mine, showing the proportion of stopes to barren ground, will very seldom indicate that more than 20 per cent. of the vein has been removed.

The second fact is, that nearly all ore-bodies are found in close association with eruptive rocks. So generally is this fact recognized than an old mining man does not like to spend money on a prospect in a new district where there is no "porphyry" ("porphyry," in the broad miners' sense, meaning any kind of eruptive rock).

In view of these two facts, it seems to me that any theory which does not recognize that only exceptional conditions could produce such exceptional results of enrichment, which does not recognize and explain the relationship between "porphyry" and ore, falls short of the mark.

My own observations as a mining engineer have led me to the following tentative views: (I.) that the majority of mineralized veins are the product of expiring vulcanism; (II.) that most of these veins were primarily mineralized by comparatively rich solutions in comparatively short periods of time; (III.) that the solutions derived their metal-values from a comparatively rich source; (IV.) that there is a barysphere containing large amounts of the useful metals; (V.) that eruptions spring from various depths and bring various kinds of magma towards the surface; and (VI.) that only those eruptions which disturb the barysphere, and bring a magma rich in metals sufficiently near the surface to be leached by vein-making solutions, are productive of valuable ore-deposits, other eruptions producing barren veins.

Ore-bodies due to magmatic segregation are not included in this general survey.

These propositions will be successively considered in the present paper.

I. The Majority of Mineralized Veins Are the Products of Expiring Vulcanism.

This proposition has been so fully demonstrated by Prof. Kemp in his very valuable article entitled The Rôle of the Igneous Rocks in the Formation of Veins,[6] that I feel it would be superfluous to add much to it.

There is, however, one small matter in which I differ with Prof. Kemp—namely, I do not think there is good reason to believe that the surface-water does not sink down into the rocks to very considerable depths. Prof. Kemp notes that many mines are dry to the point of being "dusty," at depths below 1,000 ft. This is true; but in a drift which is being rapidly driven the freshly-broken breast will always be found to be damp. The reason the lower levels of so many mines are dry and dusty is that the evaporation, slow as it is, is nevertheless faster than the very torpid movement of the ground-water. This torpidity of the ground-water in depth is caused by the "tightness" of the rocks. It is a familiar experience in mining that the ground gets tighter the deeper one goes. Of course, in individual districts there may be other obstacles, such as sills of impervious rocks or clay, preventing the ground-water from sinking into the lithosphere; but, in almost every case known to me, the tightness of the rocks in the lower levels will account for any observed diminution of water-flow. Where recent fissuring has occurred, there is generally no diminution of water-flow with depth. Indeed there may be, as at Cripple Creek, an increase.

It is often overlooked, in discussing the saturation of the ground, that in many mining districts the yearly evaporation is greater than the yearly rain-fall less the run-off. This question has been very extensively studied by the U. S. Hydrographic Survey. One of its publications, entitled The Relation of Rain-fall to Run-off, sets forth data on this subject gathered in many places. No general conclusions are drawn; but I figure that in Colorado the run-off is about one-third the rain-fall. The rain-fall varies from 12 to 24 in., or, after deducting the run-off, we have from 8 to 16 in. per year. The capacity for evaporation is more than 3 ft. per year; so that, except in those channels

[6] *Genesis of Ore-Deposits*, pp. 681 to 709, and *Trans.*, xxxi., 189 to 223.

where water quickly gathers after a rain, the country must be in a state of continual thirst, and only such water will remain under ground as is held there by capillary attraction. As depth is gained and the water-gathering channels become less frequent, we find the rocks to be moist but not always wet. Similar conditions prevail in many mining regions.

Prof. Van Hise has drawn attention to what he calls the zone of flowage, which begins at depths of from 5,000 to 12,000 m. To my mind the zone of flowage is more a matter of time, and less a matter of depth, than he considers it. I think a channel may exist at much greater depth than his limit for a short time, but when a long time is involved, I think the zone of flowage may come very close to the surface.

It seems to me entirely logical to suppose that a channel may remain open as long as it takes a laccolite to cool and yet gradually close till it is tight, except where quartz or other vein-matter has formed in it. A channel that would stay open when the surrounding rocks were quiet would have a strong tendency to close gradually if those rocks were subjected to forces which cause flexure or other movement in the earth's crust. If this supposition be well founded, it will account for those cases where the quartz is in lenticular masses and mere tight cracks in the rocks represent the veins beyond the limit of any lenticles. Such cases simply indicate that the channels have closed since the vein was formed. It is noticeable that such veins are often found in schist, or other rocks that show the effect of movement and pressure. The matter of open channels is further discussed under my third proposition.

In districts which have been fissured quite recently, like Cripple Creek, we find open fissures and much water as far down (about 1,500 ft.) as the deepest shafts have gone. But even in this camp the deep shafts in the granite are nearly dry at the bottom. Whether this is because the granite was fissured less than the eruptive rocks in the first place, or because the granite is more mobile under pressure and has closed in on its fissures, I am not prepared to say. At all events, the shafts in the granite are dry at horizons where shafts in the eruptive rocks are troubled with a great deal of water; and this water has been conclusively proved to be simply rain-water stored in the vast underground reservoir formed by the countless open

fissures in the eruptive rocks. There are no volcanic springs active in Cripple Creek to-day. Hence, I think Prof. Kemp gives a wrong impression, and one which he probably did not intend, when he says that many mines are dry to the point of being dusty in depth, which were wet near the surface. I believe that the earth is very generally impregnated with moisture; but I quite agree with Prof. Kemp that this "sea of underground water" is utterly inadequate to account for ore-bodies. In most formations, there is practically no movement in this water below the 500-ft. level. In many cases it will not run into a mine fast enough to equalize the slow evaporation; and it is beyond conception that such a torpid agent could accomplish anything in the line of vein-making before a fissure would close up, even at moderate depths.

All mining men have met with "swelling ground," and most of them have known of swelling ground that could not be accounted for by the action of the air admitted by the mine-workings. This kind of swelling is, of course, very much slower than that due to the "slacking" of lime or other rocks influenced by the air; but it shows the general tendency of rocks to close up any opening beneath the surface. Yet this tendency is always a function of time, and time is one of the most puzzling factors in any geological discussion.

It is impossible to state in years how long a geological operation lasted. The most that can be done is to compare the duration of one geological operation with that of another. To my mind, most ore-deposits show that the time consumed in their formation was very short, compared, for instance, with the time necessary to carve out the canyon of the Colorado; hence, I think that a fissure that would in time close up tight, might nevertheless stay open during the (geologically) brief interval required to cool a mass of eruptive rocks.

II. Most of These Veins Were Primarily Mineralized by Comparatively Rich Solutions in Comparatively Short Periods.

That considerable mineralization has been effected where the solutions passed through very small channels, leaving those channels very little altered, is evidenced in many places. The so-called "flats" of the Black Hills are cases in point. In the

Penobscot mine, for instance, several flat deposits of gold-ore in the sedimentary rocks have been extensively worked. The ore occurs in shoots averaging perhaps 45 ft. wide and 4.5 ft. thick. Each ore-shoot has a vertical fissure coming up through the so-called "quartzite" beneath it; and over these fissures the richest ore is found. These fissures are so small as to be easily overlooked. Those that I saw varied from 0.125 to 0.675 in. in thickness. In some places they were open, while in other places, where the width was about the same, they were filled with quartz, a circumstance which indicates that these fissures have not closed up to any great extent.

That such extensive ore-bodies should be mineralized through such small fissures suggests strongly that the solutions were comparatively rich and that they flowed for a comparatively short time. A long-continued flow, I think, would have either enlarged the little fissures or filled them completely full of quartz.

The Cortez mine, Nevada, and the Lisbon Valley copper-fields of Utah are also cases in point. At these places mineralized solutions came up through hard strata of sedimentary rocks and spread out in soft porous strata, mineralizing considerable areas. In both localities the vertical fissures are small, and show little alteration of the wall rocks. From specimens I have seen which were brought from Cobalt, Ontario, Can., I would say this is another case in point. The specimens show solid sheets of silver between comparatively unaltered walls.

That the lavas issuing from volcanoes contain large quantities of steam is well known. During the early stages of the eruption of Vesuvius, in 1898, I observed a small lava stream on two occasions, about 6 days apart. The stream was about half a mile long, and was moving very slowly. I presume it had taken three weeks to gain this length, yet it was spitting steam continually from every pore throughout its entire length. I was much impressed with two things: the great amount of steam escaping from a stream 15 ft. wide and 4 ft. deep; and the fact that the lower end continued to advance when it had only a very dull red heat. I wondered whether the escaping steam did not account for its mobility in some way. If all magmas have stored in them as great quantities of water as the Vesuvius lavas and if they tend to discharge it when brought into condi-

tions of lessened pressure we have here a source of water of no small moment. It is hardly conceivable, however, that this source can alone supply all the water used in vein-making in all cases. For instance, if a magma contained as much as 25 per cent. of water, then a spring running 10 miners' inches would in 200 years exhaust a body of the magma 40 ft. thick and 3,600 acres in extent. I think we must agree, therefore, that in some cases the volcanic waters are serviceable principally in starting and maintaining open waterways and establishing a current. In such cases they are probably joined by other waters, and the combined flow accounts for the volume of water which we find issuing from some mineral springs. Thus we find ore-deposits, such as the immense quartz veins of the San Juan, in Colorado, or the big quartz lenses of the Homestake, in S. Dakota, and of the Mother Lode, in California, that seem to have been formed by a generous supply of water; and we find other ore-bodies which indicate that very little water ever circulated through the veins, as, for instance, the ore-shoots of Goldfield, Nev., which occupy single cracks or net-works of cracks, made since the big quartz reefs were formed, and in which angular corners of the walls frequently stick out into the solid masses of sulphide ore. As the ore-bodies are found in the easily altered country-rocks as well as in the quartz ledges, such angular corners are the more remarkable. If the mineralized solutions had run a long time, these corners would have been rounded off.

At Cripple Creek, likewise, we find areas where the joints and seams of the country-rock are coated with sylvanite, and where there is no other évidence of vein-making agencies. In the veins themselves silicification is very slight. Kalgoorlie, West Australia, where a great deal of enrichment has taken place with very little silicification or other alteration of the country-rock, is another illustration. Such camps are irreconcilable, in my mind, with the theory that veins were formed by very lean solutions acting through long periods of time. Even the big low-grade quartz veins seem to indicate an agent much more active than is generally recognized. To my mind, the evidence suggests that some ore-bodies were formed by the magmatic waters or vapors alone, while others were formed or rearranged by considerable volumes of water. There is some reason to believe that the quartz of an ore-body is not always a

full-blooded brother to the mineral contents of that body; but I will not discuss that matter at this time.

In most genetic processes nature is extremely wasteful. In the formation of a sand bar in the Mississippi river, hundreds of tons of material pass down the river every day; but it is only an occasional grain that lodges on the sand-bar. Or in the growth of mounds around mineral springs, the water that flows over them is all charged with mineral matter but it is only an occasional atom that lodges on the mound. In view of this consideration, it seems to me that the theory that ore-deposits were formed by leaching the extremely lean, eruptive, or other rocks known to us on the surface, involves one of two rather untenable suppositions. Either we must conclude that nature has operated with a degree of accuracy which is almost unattainable in the laboratory; that she has leached absolutely clean the metal-contents of a rock which had the merest trace to start with, and that she has precipitated every bit of the metal so gathered in an ore-body, leaving the solution absolutely barren; or else, in case it is admitted that nature probably operated with her usual prodigality, we must assume that a tremendously large mass has been subjected to leaching action to form a relatively small ore-body. In accounting for a large ore-body, such as those of our leading copper-camps, it is difficult to understand how the leachings from such a great area as this hypothesis necessitates could have been gathered together into one underground channel. We are forced to assume that veins must branch out downwardly like the limbs and twigs of a giant tree inverted. Such conditions are contrary to ordinary observation. Veins not infrequently unite as depth is gained, but very seldom branch out with depth. This again leads to the conclusion that the solutions that formed ore-bodies were not the extremely dilute solutions which would result from leaching lean rocks.

Another reason for believing that ore-bodies were formed from comparatively rich solutions is the well-known difficulty of precipitating the last trace of any metal in solution. Whoever has had to do with a leaching process, such as cyanidation or chlorination, knows how difficult it is to get into solution the last trace of gold in the ore, and to precipitate the last trace of value from the solution. In fact, this is practically impossible;

tailings carrying from 30 to 60 cents per ton are considered in most cases to indicate good work; and foul solution that contains no more than 20 or 30 cents of value per ton is considered poor enough to throw away. Yet the surface-rocks, considered by some to be the source of the metals, are much leaner than the poorest tailings; therefore, solutions picking up metals from them must be poorer than the solutions we are forced to discard as worthless—in fact, not less dilute than the sea-water, which Don found to contain 0.071 grain of gold per ton of 2,240 lb. Don was unable to precipitate directly from this sea-water any gold at all, although he used the best precipitants under the most favorable conditions. He made his determinations by slowly evaporating several tons of sea-water and assaying the residue.

As to the time occupied in forming veins, it seems to me that most of the work has been done during the period that Prof. Kemp so fittingly calls that of "expiring vulcanism." This is a relatively short period—so short, in fact, that changes in its conditions may be noticed within a human life-time. Hot springs are very generally associated with expiring vulcanism; and nearly all the hot springs that I know of are noticeably drying up. At Steamboat springs, Nevada, at least two borings have had to be made to bring the flow up to its original capacity. Old settlers at Glenwood springs, Colorado, testify that hot water used to issue from a number of minor vents which are now dry, and that the main streams are slowly decreasing in flow. At Aguacaliente, in Sonora, the water is used for irrigation, and the abandoned fields farthest down the gulch bear mute testimony to the gradually decreasing flow. This spring is a fine example of the fact that hot mineral springs have some source other than rain-water. The only range in this dry country that receives any rain-fall to speak is the Sierra Madre, 100 miles east and across the Yaqui valley. The largest cold springs within a radius of 20 miles are only large enough to supply water for domestic use.

In discussing mineral springs, it must be borne in mind that some of them are no doubt of secondary origin. Thus, Trimble springs, Colorado, gives every evidence of having received its heat and mineral contents from the oxidization of a large body of iron pyrites.

TABLE I.—*Analyses of Eruptive Rocks from the Telluride, La Plata and Port Orford Quadrangles.*

No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
SiO_2	64.72	65.70	52.05	47.32	59.79	57.42	55.53	60.44	48.98	47.75	39.42	38.55	54.19	50.14	60.88	56.48	57.43	50.56	52.12	53.06	71.45	70.33	75.32
TiO_2	0.43	0.72		1.50	0.67	0.86	0.95	0.60	1.18	1.22		tr.	0.12	1.42	0.41	0.31	0.66	1.67	1.38	0.42	0.16	0.27	0.16
Al_2O_3	14.18	15.81	17.96	16.92	17.25	18.48	16.78	16.67	13.30	15.19	1.89	1.82	10.66	15.26	17.71	13.81	17.69	14.49	15.21	12.83	14.53	15.74	13.17
Fe_2O_3	1.58	2.54	4.09	6.21	3.60	3.74	4.06	2.31	3.67	5.05	3.42	5.55	0.52	1.19	2.92	1.78	1.59	1.78	1.83	1.20	0.49	1.43	0.27
FeO	0.40	1.62	6.33	5.94	1.59	2.10	3.35	3.09	6.92	4.95	4.29	2.17	2.26	8.75	2.17	3.95	8.48	10.20	8.75	5.10	0.94	0.83	0.98
CaO	2.62	2.56	8.64	8.51	3.77	6.84	6.96	4.22	10.66	9.98	1.10	0.85	10.76	9.84	4.32	6.69	5.72	10.13	3.75	13.71	2.01	3.38	1.48
BaO	0.28	0.12		0.07	0.14	0.15	0.13	0.12	0.06	0.08			0.04	0.03	0.06	tr.		tr.			0.03	0.09	0.23
SrO	0.21	0.03		0.06	0.11	0.08	0.11	0.11	0.05	0.05			0.05			0.02	0.02						0.02
MgO	0.50	1.62	5.03	5.69	1.24	1.71	3.00	2.18	7.03	6.87	39.68	39.06	11.90	7.21	2.21	8.67	2.73	5.90	6.01	7.50	0.30	0.53	0.42
K_2O	1.82	4.62	1.61	2.02	5.05	3.71	3.57	2.71	1.64	2.60	none.	0.05	1.03	0.95	2.68	0.46	0.58	0.38	0.48	0.05	2.55	1.87	2.14
Na_2O	3.88	3.62	2.99	2.70	5.04	4.52	4.31	5.18	2.15	2.39		0.10	1.35	2.76	4.17	5.03	7.19	2.91	4.83	3.56	7.15	4.33	4.77
P_2O_5	0.08	0.33	0.31	0.96	0.35	0.36	4.47	0.29	0.32	0.25		tr.	tr.	0.24	0.16	0.02	0.18	tr.	0.14	tr.	0.09	0.06	0.04
H_2O	9.50	0.59	0.97	1.28	0.58	0.36	0.64	1.43	1.94	2.52	9.89	11.28	5.98	2.45	2.01	2.69	2.29	1.70	4.37	2.32	0.53	1.36	0.91
CO_2					0.72		0.09	0.48	6.46	1.87		0.51	0.06				0.10	?	0.09	0.25	0.08	tr.	0.03
MnO			0.43		0.20	0.09	0.16	0.13	0.22	0.17		0.05	0.11	tr.	tr.	tr.	0.17	0.25	0.19	0.16	tr.	tr.	tr.
S												0.03	tr.	0.04	tr.	tr.	0.02	tr.	tr.	tr.	tr.	tr.	
SO_3		0.12		0.19	0.04																		
Cl		0.03			tr.	0.03																	
MoO				0.08																			
LiO					tr.	tr.	tr.	tr.				tr.	?										
V_2O_3							0.02																
FeS_2							0.04		0.54	0.02								0.28					0.09
NiO,CoO							tr.		0.03			0.18	0.03					tr.	0.08	tr.			
Cr_2O_3											0.58	0.48	0.15	tr.		tr.				0.06			
Total	100.20	100.03	100.41	99.95	100.14	100.45	100.17	99.96	100.15	100.96	99.77	100.13	99.16	99.78	99.70	99.96	99.55	100.25	99.18	100.22	100.31	100.22	100.08
Sp. gr.	2.80	2.86	2.89	2.95	2.70	2.77	2.79	2.68	2.91	2.80													

DESCRIPTION OF THE ROCKS ANALYZED, ALL FROM U. S. GEOLOGICAL SURVEY REPORTS.

Telluride Quadrangle.—No. 1, black vitrophyre from ridge east of pass between Marshall and Virginius basin. No. 2, monzonite from near lake NW. of San Miguel peak. No. 3, gabbro from Stony mountain. No. 4, gabbro-porphyry from pass south of Mount Sneffles.

La Plata Quadrangle.—No. 5, porphyry. No. 6, monzonite from Babcock peak. No. 7, monzonite facies of diorite mass. No. 8, diorite porphyry. No. 9, basic dike rock. No. 10, lamprophyre from Snowstorm peak.

Port Orford Quadrangle.—No. 11, serpentine, 12 miles north of mouth of Boulder creek. No. 12, serpentine, Iron mountain crest, near middle. No. 13, gabbro, SE. slope of Panther mountain. No. 14, gabbro, summit of Bald mountain. No. 15, gabbro, Brush creek 1.5 miles SE. Bald mountain. No. 16, gabbro, SE. ¼ sec. 7 T 343, R 142 on cross-road. No. 17, gabbro, left bank Rogue river, 2 miles below the mouth of the Illinois. No. 18, basalt, Cedar creek, 1.5 miles NE. Ophir. No. 19, basalt, near fork of West Bend trail, 2.5 miles south of Johnson creek. No. 20, basalt, Saw-tooth rock. No. 21, dacite-porphyry, 6 miles west of Big Bend of Rogue river. No. 22, dacite-porphyry, head of Boulder creek. No. 23, dacite-porphyry, south slope of Bald mountain.

TABLE II.—*Analyses of Spring-Waters.*

Parts in one thousand.

No.	1	2	3	4	5	6	7	8	9	10	11	12
Na	0.1042	0.7743	0.3554	0.3040	0.6116						0.0310	0.0020
K	tr.	0.0669	0.0191	0.0094	0.0630					0.1285	0.0372	0.0128
Ca	0.5060	0.0305	0.0367	0.0121	0.0589					1.0789		0.0012
Mg		0.0010	0.0034	0.0004	0.0604					0.2352		
Ba										tr.		
Sr												
Li	tr.									0.0003		
Fe	tr.									0.0027		
Mn	tr.									0.0009		
Cl	tr.	0.9697	0.2396	0.2070	0.2272	0.9524				4.2730	0.0480	
Br										0.0025		
I										tr.		
Fl												
CO_2	0.0852		tr.		0.5787	0.1776	0.2624	1.7513		0.1792	0.0383	0.0089
SO_3	0.1614	0.3555	0.3901	0.3492	0.3181	0.1039				2.0318		0.0040
HPO_4	tr.								tr.	0.0004		0.0179
B_4O_7						0.2174	1.8784	2.4043	tr.	tr.		
Al_2O_3	tr.	0.0010			0.0018	0.0003				0.0022		0.0012
SiO_2	tr.	0.2788	0.1186	0.1310	0.1220	0.8106	0.0371	0.0418	0.2464	0.0080		0.0317
H										0.0030		
Organic	tr.						0.0050	0.0076				
O		0.0194	0.0255	0.0080	0.0325							
H_2S	0.0500					0.0005	0.0045	0.0007				
RHS and S						0.0069						
As_2O_5						0.0036						
SbO_3						0.0005						
P_2O_5						0.0006						
HgS						tr.						
FeO						0.0002						
MgO						0.0005						
Na_2O						0.9193						
CaO						0.0005						
K_2O						0.1246						
$FeCO_3$								0.0010	tr.	2.0398		0.0109
NaCl							1.1027	1.0397	13.6226			0.0248
Alk. Carb							2.0075	0.3809	0.4768		0.0154	
KSO_4									0.8005			
$CaSO_4$							0.0234		1.1548			
$NaSO_4$								0.6890				
MgCl									0.1637			
KCl							0.0470	0.0747				
NaBr									0.0704			
Total	0.9068	2.5171	1.1834	1.0211	2.0692	2.8194	5.3675	6.3910	16.0352	9.9814	0.1699	0.1149

SPRINGS.

No. 1, Sulphur springs, Los Angeles; *Annual Report U. S. Geological Survey*, p. 195, 1876. No. 2, Hot spring at Hot Spring station, C. P. R. R.; *Chamberlin and Salisbury's Geology*, pp. 224–225. No. 3, Hot springs at the base of the Granite mountains, Nevada; *Chamberlin and Salisbury's Geology*, pp. 224-225. No. 4, Boiling spring at Honey Lake valley, California; *Chamberlin and Salisbury's Geology*, pp. 224–225. No. 5, Warm spring, Mono basin, California; *Bulletin No. 9, U. S. Geological Survey*, p. 27. No. 6, Steamboat springs, Nevada; G. F. Becker, *Geology of the Quicksilver Deposits of the Pacific Slope; Monograph* xiii., *U. S. Geological Survey*, p. 347. No. 7 and No. 8, two different shafts at Sulphur Bank, California; G. F. Becker, *Geology of the Quicksilver Deposits of the Pacific Slope; Monograph* xiii, *U. S. Geological Survey*, p. 259. No. 9, Glenwood springs, Colorado; *Glenwood Springs Hotel Pamphlet.* No. 10, artesian well at Sheboygan, Wisconsin; C. F. Chandler, *American Chemist*, p. 370, 1876. No. 11, the Mississippi river; W. J. Jones, *Report Louisiana State Board of Health*, p. 370, 1882. No. 12, the Sacramento river; W. J. Jones, *Report California State Board of Health*, 1878.

Table I. contains analyses of 23 eruptive rocks, and Table II. the analyses of 12 spring-waters, the first nine of the latter being hot springs, the tenth an artesian well, and the eleventh and twelfth river-waters. The rock analyses, which are from representative surface eruptives, show that these rocks must be very lean indeed in the useful metals. Mr. Waldemar Lindgren[7] mentions the finding of traces of pyrite, chalcopyrite and galena in the gray gneiss of Freiberg. Prof. Kemp mentions the finding of various metals in various eruptive rocks, but does not give any quantitative analyses.[8]

Don was unable to find any gold at all in the rocks he examined except in association with iron pyrites, which latter gave evidence of being the result of vein-making agencies. Of course, it may be said that all the analyses of the eruptive rocks are made after they have been leached out. If it could be shown that the surface eruptive rocks have a tendency to throw off metals, as they do steam and sulphur, during the cooling process this would remove many of my objections to considering them the source of the metals in our ore-bodies. In the lack of such proof, however, we must recognize that they are extremely lean, and therefore a very unlikely source of mineral wealth.

Of the four rocks from the Telluride quadrangle only one shows manganese; yet rhodonite and rhodocrosite are very common to the veins of this district. Of the six analyses from the La Plata quadrangle, every one shows manganese; yet it has been my observation that manganese is a rare constituent of the veins of this quadrangle. In the 13 analyses of rock from the Port Orford quadrangle a wide range of minerals is seen, which often are found in veins, yet the veins of this locality contain little but quartz, pyrite, chalcopyrite and gold.[9]

The table of spring-waters was rather surprising to me in that it shows that an artesian well-water may contain as much mineral matter in solution as the average hot spring. I do not see that a comparison of the minerals found in hot springs with those minerals found in the eruptive rocks is very instructive. Unfortunately, I have no complete analyses of all the rocks im-

[7] Metasomatic Processes in Fissure-Veins, *Trans.*, xxx., 659 *et seq.*

[8] The Rôle of the Igneous Rocks in the Formation of Veins, *Genesis of Ore-Deposits*, pp. 681 to 709, and *Trans.*, xxxi., 169 to 198 (1901.)

[9] *Port Orford Folio, U. S. Geological Survey.*

mediately surrounding a hot spring. If such analyses were available they would be very instructive. As it is, the only distinguishing characteristic of hot springs brought out by the analyses is the presence of sulphur and sulphur gases and of chlorine combinations. Fresh lava, we know, gives off fumes of sulphur and chlorine; hence it is natural to connect hot sulphur springs with fresh eruptives.

The analyses given in Table I. show very few of the useful metals in solution, but Posepny in his *Genesis of Ore-Deposits* mentions that lead occurs in the springs of Rippoldsau (according to Will, 1.6 to 3.7 mg. per ton), and in the Kissingen spring (13 mg. per ton), and quotes from G. Bischof, as follows, the maxima found in mineral springs up to 1854, in milligrams per ton of water:[10] Arsenious acid, 1.5; antimony oxide, 0.1; zinc oxide (sulphate), 13.3; lead oxide, 0.1; copper oxide, 6.4; tin oxide, 0.1.

It is not mentioned whether or not any of these may have been enriched in a secondary way. It would not, however, be surprising if no spring among those analyzed had been primarily enriched with useful metals. We have only a few analyses; ore-bodies are very rare things, and give evidence of having been made in comparatively short periods, while veins are very common things; so that, granted the hot springs are making veins, the probabilities are that they are nearly all making barren veins or barren parts of veins. Posepny found that the Sulphur Bank spring, whose enrichment is probably primary, carried small quantities of mercurial sulphide in suspension. At least he found this material on his filter-paper after filtering the water, but he found only a trace of mercury in the water. Unless we accept this case, I have not read of any in which a mineral spring has been "caught in the act" of making an ore-body, and this only emphasizes my belief that ore-bodies are formed in relatively short periods of time. Ore-bodies seem to have been formed in every geological age since early paleozoic times; and if we grant that each mineralized district was enriched in a relatively short period, it would not be strange if very few ore-bodies, or none at all, were in process of formation at the present moment.

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[10] *Genesis of Ore-Deposits*, p. 47.

We know that many veins are now in process of formation; and we find that many springs carry in solution the materials found in veins, showing that nature is prodigal in her methods. Probably a small part only of the vein-making contents of any spring is deposited in the underground channel; the rest "goes down the creek." If we should find a mineral spring in the process of forming an ore-body, we might expect most of the metallic constituents of the solution to have remained in it after it issued from the ground.

It is true that we analyze spring-waters after they have passed through the zone of precipitation; and it is conceivable that a water showing at the surface no trace of metal may have carried material quantities of metal before it reached the zone of precipitation. But in that case the water must have been completely robbed of metal-values in the zone of precipitation; and it is hard to understand how such a clean precipitation could be effected by such precipitating-agents as we attribute to the superficial zone. It is easier to believe that we have not as yet found an ore-body forming or a spring engaged in forming one.

It has been asserted lately that the curative effect of some mineral springs is largely due to radio-activity. Nearly all the radio-active metals are of high specific gravity; so that the association of mineral springs with ore-bodies or with magmas rich in heavy metals is further indicated in this way.

Glenwood springs, Colorado, and Hot springs, Arkansas, have both been found to be slightly radio-active. But the springs most remarkable in this respect hitherto discovered are the Doughty springs, in Delta county, Colo. Dr. Wm. P. Headden has made some very fine radiographs from the sinter surrounding these springs.[11]

There are several springs, and the analyses differ somewhat; but the principal radio-active spring (called the Drinking spring) has the following analysis, in parts per 1,000: Na, 0.045863; K, 0.001576; Li, 0.000446; NH_4, 0.000068; Ca, 0.005272; Ba, 0.000192; Sr, 0.000150; Mg, 0.003230; Fe, 0.000026; Al, 0.000054; Mn, 0.000060; Zn, trace; Cl, 0.019762; Br, 0.000065; I, trace; SO_4, 0.013022; SiO_2, 0.000696; BO_2, 0.000174; total, 0.090656.

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[11] *Proceedings Colorado Scientific Society*, vol. viii., pp. 1 to 30 (1905).

These are not hot springs; and whether or not they are springs of primary enrichment is not clearly shown. It will be noted from the analysis that Na, Cl, and SO_4 are the principal substances found in solution; but the distinguishing feature of the spring is the barium sulphate which the water is actively precipitating on the mound around the spring. Dr. Headden says: "The deposition of practically pure baric sulphate by a mineral spring is, so far as I have been able to find, a unique fact."[12] The radium is intimately associated with the barium sulphate.

III. The Solutions Derived Their Metal-Values from a Comparatively Rich Source.

This follows necessarily, if it be admitted that ore-bodies give unmistakable evidence that they were formed by rich solutions. If we believe that the source of the values was the surface-rocks, but admit that "expiring vulcanism" set matters in motion for vein-making, we should expect all veins to show a certain amount of concentration of mineral values; at least all of the veins in the vicinity of eruptive rocks. But the complete barrenness of most veins, even in mining districts, is one of the hard facts that are pressed home upon every experienced mining man. There are also, of course, countless absolutely barren veins and dislocations outside the mining districts.

Some writers suppose that the surface eruptive rocks carry appreciably more mineral than other rocks, and that they are the source of the mineral in the ore-deposits. It is, however, a common observation that the characteristic eruptive rocks of a mining camp are not confined to the mineralized area. As examples, I will mention Cripple Creek, Colo., The Homestake, S. D., Kalgoorlie, W. A., Monte Christo, Wash., Goldfield, Nev., Arizona King, Ariz., and El Trinidad, Sonora. It is also common that these rocks carry either no values at all or a metal that is not characteristic of the camp. In the analyses given in Table I. it will be noticed that the eruptives of the La Plata quadrangle all carry manganese, while only one of those in the Telluride quadrangle carries manganese. Rhodocrosite and rhodonite are very prevalent in the Telluride quadrangle, but only occasionally met with in the La Platas, if my own

[12] *Proceedings Colorado Scientific Society*, vol. viii., p. 26 (1905).

limited observations are to be relied upon. I think that all this points to the exceptional and unusual sources for such ore-bodies.

The principal objection to a deep-seated and rich source for the mineralization of veins which I have read is that of Van Hise, who, calling attention to the limits of the zone of fracture, says:[13]

"On the assumption (a) that the strength of the rocks is the same as on the surface; (b) that the rocks are all of the same kind; (c) that the temperature is the same at the surface; (d) that the water present does not make any difference in the character of deformation; (e) that the rocks yield as readily by fracture as by flowage; (f) that the rocks break as readily by fracture when the deformation is slow as when it is rapid; (g) that the rocks are among the strongest .... a fissure would close almost at once at a depth of 12,000 meters."

He concludes that the practical limit in depth of the zone of fracture is about 5,000 meters.

The resistance of a large number of rocks to binding and crushing has been determined; but such figures give us no satisfactory basis for the calculation here involved. It is necessary to consider also the "arching" of any material, even of crushed material. Loose coke and ore have no strength whatever to resist flexure, yet they will "bridge" a blast-furnace, and broken ore will often arch in an ore-chute and choke it up.

If Prof. Van Hise's conclusion is correct, why does not rock-flowage prevent the continued existence of mountain peaks 5,000 m. high, and of springs at the base of such masses?[14] If a fissure could not exist at a given depth, how can a peak exist to an equal height? Such a peak may represent the foot-wall of a rather flat fissure, the opposite side of which has been removed. Would the absence of the opposite side prevent the action of rock-flowage? Has the phenomenon of rock-flowage ever been observed, bulging out the solid rock at the base of a peak or precipice?

And if a spring can flow from under a mass of rock 20,000 ft. high, why could not a fissure exist 20,000 ft. below the surface?

Again, the effect of rock-flowage, whatever it may be, is ad-

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[13] *Op. cit.*, p. 188 (?).

[14] According to Mr. M. W. Conway's *Climbing in the Himalayas*, Peak K2 of that range is 28,000 ft. above sea-level, and many other peaks exceed 20,000 ft. In Bolivia there are mountains rising somewhat abruptly 21,000 or 22,000 ft. from sea-level. Many other instances could be cited, from British Columbia and Alaska.

mittedly slow, and must be subject to arrest or diversion by the greater force of rock-movements in mass. Such movements, indicated in innumerable instances by their geological effects, are continually presented for our observation in non-volcanic earthquakes, like those at Charleston, San Francisco, Jamaica, etc., and are reported daily by the seismometers of the world. Is it reasonable to believe that a movement felt at a horizontal distance of 10,000 miles has had no effect below the depth of 5,000 or 12,000 m. (3 or 7 miles)? If it has had such effect, it must have counteracted the previous work of rock-flowage, and opened new fissures, upon which that slow agency must commence operations *de novo*.

Very recent seismometric observations (preceding by a few weeks the Jamaica earthquake of January, 1907) reported a submarine earthquake in the deepest part of the Pacific, far exceeding in intensity and energy anything hitherto observed on land. Such earthquakes occur under, say, 24,000 ft. of sea-water (the maximum depth off the coast of Asia is greater than that), equivalent in weight to 10,000 ft. of rock; yet they not only break the sea-bottom, but possess surplus energy enough to lift the sea itself, producing enormous tidal waves. May we not safely conclude that they might still occur under a greater superincumbent pressure, and, in particular, that 15,000 or 20,000 ft. of rock, the pressure of which, producing rock-flowage, operates much more slowly than an equal pressure producing water-flowage, would not necessarily prevent an earthquake sufficient to make and, for a time at least, maintain fissures?[15]

Again, it is not proved that the pressure which would close an open crack by rock-flowage would be sufficient to change the density of the rock itself, and close all pores and capillary passages in it. On the contrary, it is probable that the slow deformation of rocks under pressure takes place without fracture or change of density. This, at least, is indicated by the early experiments of Sorby and others, and by the actual observed conditions of limestone, etc., which have been thus changed in form, yet show their original structure. It follows, apparently, that the assumed lower limit of rock-flowage is not necessarily the limit of rock permeability, and also that any interruption

[15] This consideration was suggested to me in a private communication by the Secretary of the Institute.

of the closing of a fissure by rock-flowage might continue for an indefinite period, or until rock-flowage in new directions, or a forced change in the density of the rock, had completed the process thus interrupted. This leaves room for the hypothesis here advanced, which requires, not the endless persistence, but only the existence for a sufficient period, of deep channels of circulation.

Now, there is here no question of an absolutely open fissure, with walls nowhere in contact. On the contrary, fissures are almost always formed by movements of one wall relatively to the other, and are almost always "closed" to a certain extent by the "misfit" contact of the walls in their new relative position. This leaves more or less continuous and connected channels for underground waters and gases, the further closing of which by the pressure of the inclosing rocks may be long delayed by the fact that the pressure tending to close the openings must overcome the resistance of the solid masses which are keeping them open and the "arching" of the material around such openings. It must be admitted that the complete "squeezing out" of all such residual and interstitial cavities is likely to be a much slower process than the closing of altogether open and continuous fissures.

In view of the foregoing considerations, I can see no reason why small open channels may not exist as far below the surface of the earth as mountain peaks extend above the average gravity-level; and, moreover, as these channels would doubtless be filled with water, a practically incompressible liquid, having material weight of its own, I think we may conclude that they would resist closing all the more on that account, and, indeed, could not be completely closed, unless the water were provided with the means of escape—in other words, with channels!

Prof. Van Hise calls attention to the fact that at a certain depth the critical temperature of water (360° C.) would be reached, and that it could not exist as water below that depth. But it does not follow that the form in which it could exist would not possess equal density and solvent power.

According to the rate of increase assumed by many writers—1° C. for every 30 m. of added depth—the critical temperature would be reached at 10,350 m., if 15° C. be taken as the temperature of the surface. But we are scarcely warranted in as-

suming that rate as uniform to great depths. M. Walferdin, by a series of careful observations in two shafts at Creuzot, proved that down to a depth of 1,800 ft. the increase in temperature amounted to 1° F. for every 55 ft. of descent; but below the depth named the rate of increase was as great as 1° F. for every 44 ft. On the other hand, in the great boring of Grenelle, at Paris, the increase in temperature down to 740 ft. was 1° F. for every 50 ft.; but from 740 to 1,600 ft. it diminished to 1° F. for every 75 ft. A similar remarkable fact was shown in the Sperenberg boring, near Berlin, where the rate of increase for 1,900 ft. was 1° F. for every 55 ft., and for the next 2,000 ft. only 1° F. for every 62 ft. In the deep well at Buda Pesth there was actually found a decline in temperature below the depth of 3,000 ft.

A list of 164 wells, from 400 to 2,220 ft. deep, bored in the United States,[16] shows irregularities of temperature not to be referred to any general formula. To the rule mentioned above—namely, 1° C. for every 30 m. of added depth—there are far more exceptions than confirmations. No doubt these variations are due to local physical or chemical causes; and, in like manner, it must be conceded that under conditions of expiring vulcanism very high temperatures may prevail, probably even beyond the critical temperature of water. But it seems unsafe to reckon upon a transcendently hot interior of the mass of the earth.

Finally, it is not safe to assume that this mass is under such pressure as to be precluded from all movement whatever below a few thousand feet of its 4,000 miles of radius; and a movement causing displacement would give opportunity for the rise of a heavy magma to a higher level.

In view of the above considerations, I find nothing precluding the idea that the solutions which have formed ore-bodies have had comparatively rich sources, and that these sources were very likely laccolites of heavy magmas, brought up from the barysphere into the lower part of the zone of fracture.

IV. There is a Barysphere Containing Large Amounts of the Useful Metals.

This, I think, has never been seriously questioned. Physicists and astronomers have weighed the earth and found it not

[16] *Water Supply and Irrigation Paper* No. 149, *U. S. Geological Survey*.

"wanting," but over-weight. R. von Sternbeck determined the specific gravity of the earth to be 5.6, while the average density of the surface-rock is 2.5. Chamberlin and Salisbury in their treatise on geology give the specific gravity of the earth as 5.57, and that of the lithosphere as 2.7. There is a theory that the greater relative weight of the earth is caused by pressure alone; that the material is the same throughout, but that the pressure has made the interior rocks more dense. I believe it has been demonstrated that rocks do yield somewhat to such pressure as may be artificially applied; but such evidence comes far short of the proof here required. To satisfy this theory it would be necessary for the rocks to be compressed, near the center of the earth, to one-fourth their volume at the surface. Against this hypothesis, we have the facts that magmas of very different specific gravity issue from the interior of the earth, and that eruptive rocks, as a class, are heavier than surface-rocks.

Van Hise remarks:[17]

> "It is noticeable in the altered rocks that in proportion as deep-seated metamorphism is advanced the heavier (of the above) minerals appear."

V. Eruptions Spring from Various Depths and Bring Various Kinds of Magma Toward the Surface.

This seems to me to be shown by what is known of eruptions. As vents filled with molten material would not be subject to the causes limiting the depths of water-channels there is no limit to the depths to which we may expect them to extend. I understand that the majority of both astronomers and geologists regard the earth's interior as solid and rigid as steel. Eruptions are generally considered to be the result of local stress and friction. Just what is the cause of the stress and just how the force is applied are matters of discussion. A very simple explanation, but one which does not seem to appeal to most writers, is that the axis of the earth is gradually shifting, and the earth being an oblate spheroid has to keep rearranging its mass to suit the new positions of the axis.

At Cananea, Sonora, in 1902, I saw an illustration of a volcano on a very small scale. A block of heavy iron gossan, constituting, roughly, a cube of about 200 ft. on a side, or 8,000,-

[17] *Op. cit.*, p. 188 (?).

000 cu. ft. in volume, had been undermined, and slipped down 6 ft., crushing the timbers. The heat produced underground, near the foot-wall, was intense, and on the surface two or three small jets of steam appeared. If a little block of ground like that, slipping 6 ft., could generate sufficient heat to produce such jets of steam, it is easy to understand how the movements of a large region might incidentally produce a volcano or two. Suppose, for example, that an eruption is caused by a force which produces faulting under great pressure. The first effect may be confined to the lithosphere, so that barren magmas are squeezed out. But, as the force gathers intensity, the fault extends into the barysphere, and some of the latter is forced upward, crowding out the lighter lavas above it. By reason of its greater specific gravity it floats the lighter rocks above it, and forms, within the reach of underground waters, a laccolite, which may subsequently become the source of valuable mineral deposits.

Chester Wells Purington, in the Telluride Folio of the U. S. Geological Survey, says, in effect, that the basic parts of eruptive rocks, such as hornblende, augite, biotite, contain more of the useful metals than the other parts, and deems it probable that the mother magma had a basic portion, which might be the source of the metals in the ore-deposits. His idea and mine are not widely at variance.

VI. Only Those Eruptions which Disturb the Barysphere and Bring a Magma Rich in Metals Sufficiently Near the Surface to be Leached by Vein-Making Solutions are Productive of Valuable Ore-Deposits, Other Eruptions Producing Barren Veins.

In support of this proposition there are many indications not mentioned above. In many mining districts there have been successive eruptions, but the ore-bodies are definitely associated with one eruption and appear to have no relationship with the others. Thus, at Butte, Mont., the ore-bodies are associated with a quartz-porphyry eruption, while the acid granite, basic granite and rhyolite eruptions produced no ore-bodies. At Cripple Creek we have a whole series of eruptions; but the mineralization of the veins followed on the heels of the nepheline-basalt eruption.

We often find in a mining district several series of veins, only one of which bears mineral values. At Rico, Colo., for instance, there is a series, terminating at the so-called "contact," which has been enriched with silver and other metals; and there is another series of strong quartz veins not thus enriched. These facts suggest that, among the eruptions, one must have been radically different from the others. Yet analyses of the surface-rocks do not reveal any startling differences. It seems evident that the mineralized series of veins must have been formed from a source radically different from that of the barren ones. My explanation is, that in a series of eruptions, one may have been sufficiently deep-seated to disturb the barysphere and force some of its material toward the surface. It would never reach the surface, because its specific gravity would cause it to form, sooner or later, a laccolite, floating the surface-rocks. But, in exceptional cases, it might rise far enough to become subject to the agencies which make mineral-bearing veins.

I presume that the barysphere includes different kinds of unsegregated magmas. It may be built up concentrically, or it may be simply spotted, as the surface is, with different rocks. A laccolite of magma rich in copper might give rise to a surface region yielding copper; one rich in gold might become the origin of a gold-bearing district, etc.

I do not mean that the constituents of the magma would govern entirely. It is conceivable that conditions of the solution and precipitation of the metals might also be influential. But this general hypothesis suggests an explanation of those cases in which totally different kinds of ore-deposits occur in the same surface-rocks, close together, and under conditions apparently similar, except as to age. Butte, Rico and Leadville are cases in point. At Butte there is a great mass of dark, basic granite, which contains two vein-systems. In the southern part of the camp are the famous veins of copper, containing sulphide ore-bodies with more or less quartz. The northern system produces ores of silver, lead, zinc and iron. Prof. Kemp has called attention to the fact that the northern ores are abundantly associated with manganese minerals, especially rhodonite; that no manganese occurs in the copper belt and no copper in the silver belt; and infers that "such results could originate only in different deep-seated sources."

This hypothesis offers also an explanation of cases in which there is an extensive surface-area, showing similar eruptive rocks throughout, yet only a small part of which has been mineralized. Thus, in areas like southern Nevada and the Yaqui River country of Sonora, there are vast quantities of eruptive rocks of much the same kinds, but only in isolated localities have paying veins been found. Sometimes these localities are, and sometimes they are not, characterized by a trifling exposure of a peculiar eruptive rock. In the former case, the trifling surface manifestation seems utterly inadequate to account for the very exceptional vein-contents of the localities.

Cripple Creek is another case in point. The whole Arkansas plateau is prolific of all the rocks characteristic of Cripple Creek (unless, it may be, the basalt dikes). The largest masses of phonolite I know of are found, as in Grouse mountain and Little Pisgah peak, outside the productive area, while around Saddle mountain and at Bare hills there are large masses of andesitic breccia, yet no ore-deposits. At Globe, Ariz., there is an extensive area, northwest of the camp, that has the same formation as that surrounding the mines; but thus far no ore-deposits of value have been found in it, though it is not lacking in veins.

Of Grass valley, Cal., the U. S. Geological Survey folio says: "The veins occur in almost any one of the many rocks making up the bed-rock series. Excellent mines are located in the grano-diorite, diabase, slate and schists." Evidently the surface-eruptives did not govern in this case.

In the case of several eruptions, only one of which is associated with ore-bodies, the theory would be that the one associated with the ore-bodies was the deep-seated one, which brought some of the mineralized magma within reach of the vein-making agencies, and that, while the surface-manifestation may have been weak, and not different essentially from other eruptions in the same locality, the eruption in depth was radically different.

As to the series of veins in a given district, we would say that the barren ones were the products of the shallow eruptions, while the rich ones were the product of an eruption that brought a rich magma surface-ward. In the case of a large area of eruptive rocks containing a very small mineralized dis-

trict, it seems to me hard to understand why the mineralization is not much more general, if the surface eruptives are accountable for the metal values. If, however, these values came from a relatively small buried mass of very richly mineralized eruptive rock, the restricted mineralized surface-area is at once explained.

Again, there are occasional mining districts in which no eruptive rocks at all appear on the surface, such as the zinc-lead deposits of southwestern Illinois, and the Otago gold-fields of the South Island of New Zealand. (The latter are described by Rickard in his discussion of Posepny's *Genesis of Ore-Deposits*.) In such cases the influence of a richly mineralized underlying laccolite is highly reasonable.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Blast-Furnace Practice.*

BY T. F. WITHERBEE, DURANGO, MEXICO.

(New York Meeting, April, 1907.)

Discussion of the paper of F. L. Grammer, Flue-Dirt and Top-Pressure in Iron Blast-Furnaces: A Study of the Influences Controlling Them, *Trans.*, xxxiv., 92 to 105; and the paper of J. E. Johnson, Jr., Physical Action of the Blast-Furnace, *Trans.*, xxxvi., 454 to 488.

THE matter of blast-penetration is merely a question of blast-velocity through the tuyeres, and when the distribution of the charge admits of no variation or control, as is the case with ordinary double and single bells, it involves merely that the adjustment of total tuyere-area to blast-volume shall be determined for average conditions by direct experiment and maintained by slight changes of blast-volume. Penetration is perhaps the most important factor connected with the practical blowing of a furnace.

When proper penetration is once attained the relation of tuyere-area to blast-volume admits of change only to a very limited extent. I can testify to the value of probing with an iron (not a steel) rod, as described by Mr. Johnson, to ascertain the conditions at the tuyeres, and I would add that it is about as useful considerably higher up. However, its reading is not quite so simple as might be supposed, as it may deceive if judged by its temperature (color) alone, and there should also be taken into account the location of the hard and soft zones, if any, when passing the rod across the crucible, for which reason the furnace-manager or the one who "wants to know" should assist in the probing.

If the rod should show the crucible to be hot at the walls

* In view of the fact that the authors of contributions to discussions in this department habitually comment upon more than one preceding paper, so that it is impracticable to class such a contribution as a discussion of any particular paper alone, it has been deemed best to use the general heading "Blast-Furnace Practice," as was done for the same reason in former volumes of the *Transactions*.

and cold in the center, and also develop a soft center, or even a cavity, it is *prima facie* evidence that the furnace is already overblown.

In such a case of doubt it is best to "blow up" for half an hour or so, and then test again, when if found abnormally hot at the center, or hotter than at the wall, overblowing has occurred. Quite often, when every other symptom has indicated the advisability of a temporary slackening of the blast, the test-rod has unmistakably demanded more blast. Where it is the practice to blow a constant volume of blast without watching and controlling penetration, it may well be that some serious derangements are due to such neglect. Some may object to any change of blast-volume, and it may not be so much of a necessity with Bessemer and basic furnaces, especially in the case of a group of furnaces having access to a "mixer" to average up the quality of the iron; but at isolated furnaces, especially foundry-iron furnaces, restricted to only three grades, with no outlet for "off-iron" except the bargain-counter, slight changes in blast-volume offer certainly the promptest and probably the best remedy available at present: while the use of charging-apparatus having controllable distribution and mixers may be the better remedy of the future. Had I known the value of the test-rod way back in the 70's and 80's I am sure I should have escaped 90 per cent. of all the troubles that occurred, and incidentally should have missed some "experience" and "practice," which, while not entirely devoid of value, cost somebody more than it was worth. It is evident that testing with a rod has been independently taken up by many furnace-men. Mr. Edgar S. Cook told me at the Monterey (Mexico) meeting of the Institute, that he had used it, presumably during his active furnace-practice, which would date back some considerable time. My experience with it began in December, 1895, after having discovered a "core" in the South Chicago Calumet furnace by other means.

In watching inside-conditions with an iron rod, while removing the core, the value of the test-rod at once became evident. I consider it the most valuable piece of "apparatus" available to the furnace-manager known to-day, and Mr. Johnson will doubtless receive the thanks of all who were not familiar with it. It would seem to be entirely a matter of choice whether

"top-pressure" exists at all or not, as the same gases that may have been under pressure at the furnace-top are afterwards burned at stoves and boilers under the conditions of a partial vacuum, notwithstanding their greatly increased volume due to the addition of the air of combustion and their expansion by combustion, finally passing into the chimney at about furnace-top temperature; and it is only necessary to provide adequate down-comer flue- and valve-area and sufficient chimney-draft to eliminate it entirely. However, for reasons given later by the late Mr. Thomas Whitwell, some top- or flue-pressure should be maintained, but such pressure should be had by gas-valve adjustment at stoves and boilers.

Any top-pressure (9 in. or thereabout of water), as noted by Mr. Grammer and Mr. Firmstone, was probably due to inadequate down-comer flues and valves, or to the same obstructed by flue-dust. But, whatever the cause, such pressure is of no use, may be positively harmful, and should be avoided.

An instance of the destructive effect of gas-pressure occurred at a coke-furnace using Lake ores. The gas in the Spearman burners burned with a series of puffs and explosions, with a loud drumming noise, and had set up a shaking, swaying movement of the stoves, amounting to more than 0.5 in. at the top, with the result that at about three-quarters down the checker-work the bricks were ground to powder, the checker-work settling down from the top into a heap of loose bricks. The shaking was at once recognized as due to the puffy combustion, from the same thing once having occurred with an iron-pipe stove, though from a different cause. As the pressure was the only abnormal condition known, the cause of the explosive combustion was sought in that direction. The pressure was found to be as follows: At top, 9 in.; at outlet of first dust-catcher, 8 in.; at second dust-catcher, 8 in.; at outlet of second dust-catcher, 2.5 in.; and at all burners, 0.5 in. of water.

By removing the diaphragm of the second dust-catcher, the pressure fell to 2.5 in. all around, except at the top, where it was 3.5. in., the gas burned quietly, and all shaking ceased at stoves.

An instance of high gas-pressure due to obstructed flues also happened at a coke-furnace using very poorly-made coke. The tar condensed in the dust-catcher goose-neck, and cemented

the coke-dust as it came along, until it had closed the flue to about 12 in. Then came some large coke and choked it so much that the loaded bell would not open. The holding-up of the bell was thought to be due to the tar actually cementing it to the hopper-ring, but finally it was noticed that it would dump when the blast was off, which located the difficulty. That has occurred three times, giving no sign until it became an accomplished fact.

Abnormal pressure is probably due, in some cases, to too-small down-comers which have not been based on any consideration of the volume of gas to be carried. This I infer from a comparison of a large number of furnaces which show no harmony as to flue and down-comer areas. Many years ago, Truran laid down the rule of one-sixth of the stock-line area, and such rule applied now would call for an increased size at many furnaces, but our blast-furnace designers doubtless now have something more modern and exact.

As to what flue-pressure should be, the late Mr. Thomas Whitwell's advice as to handling gas in connection with his stoves may be as good now as when given 30 years ago. He said: "Always keep a little pressure in the gas-flue, just enough so that there is a faint smell of unburned gas, and then you will know that it is not burning in the flues." Probably about 3 in. of water-pressure would be ample.

I do not know who Mr. Johnson aimed at in his discussion of "blast-wandering." I used the phrase in my paper on special forms of charging-apparatus,[1] though the expression was not original with me, having been given me by a furnace-man of 35 years' experience, beginning with anthracite coal and magnetic ore and ending with a group or plant of 18 or 19 blast-furnaces using coke and Lake ores, whose fuel economy and regularity of working have never been equaled, so far as I know—a man naturally conservative, who never announces anything on furnace-practice that is not based on repeatedly observed facts, and as I most fully agree with him, also on account of observed facts, it seems proper to defend the claim. But, first of all, it will be necessary to state what was meant by "blast-wandering," and on that point I can only speak for myself. As used in the paper referred to, a careful reading of it

[1] *Trans.*, xxxv., 575 to 586.

will show that only wandering through the tuyeres was referred to, and of which I believe indisputable evidence was cited in the fact that some tuyere-pipes were 400° or 500° F. hotter than others, and also the device of Mr. Hartman, which showed a difference of pressure in different tuyere-pipes; and I also might have mentioned the experiment of another furnace-man who introduced a small turbine-wheel into the belly-pipes, the shaft of which projected out through a bushing in the peep-hole. The different numbers of revolutions shown at different tuyeres were assumed to be due to differences in blast-volume passing into the furnace, and therefore to demonstrate blast-wandering. Now, if there is any other explanation for the above phenomena than blast-wandering, it would be interesting to hear it. Blast-wandering, as understood by myself, means nothing more or less than following lines of least resistance, and that does not necessarily imply that such lines are produced by the blast, but that the blast takes advantage of them and so at times does great damage, and in that view the burning through of the linings at Sydney, as related by Mr. Baker,[2] the case cited by Mr. Porter,[3] and my own experience at Mayville, are all cases in point. In old anthracite practice it was a common saying: "We are working a lot of little furnaces inside of a big one," meaning that the tuyeres were working somewhat independently of each other. Of blast-wandering in the shaft of a blast-furnace I can cite but a single example—that of a furnace that had been scaffolded by alternate under- and over-blowing, while using all coke. To remove the scaffold, six holes had been cut through the shell and lining 35 ft. up, or just half the height of the stack. After normal conditions were restored, five of the holes were solidly bricked up and one was only loosely stopped by bricks, backed up by dry sand, so that it could be easily opened to see what was going on inside. Sometimes the stock at the walls was at a bright red, and was moving freely downwards, and there was a free escape of gas, but never enough to indicate much pressure. At other times all would be black, with only sluggish movement of materials, and no gas escape, a rod showing a hot center, and a center descent of the charges. All this taking place without any change

[2] *Trans.*, xxxv., 244 to 255.

[3] *Trans.*, xxxv., 1017.

in the charging or blowing. Red-hot tuyere-pipes and a few holes cut through the shell and the lining between the mantel and the stock-line might furnish some valuable information, even at the present time. I will add that channels of least resistance are formed by any kind of bell-charging—at the inner and outer edges of the inverted V ring of materials in case of a single bell, and, in addition, in case of a double bell, a channel between an outer ring of material and a center heap, if the double bell has that kind of distribution—by reason of the coarser part of the charge rolling from the apexes and so separating from the finer part, and I have had abundant evidence that such rings and heaps descend very low in the furnace practically intact.

During the last two years I have been experimenting with a new form of bell, which gives controllable distribution, consisting of one bell on top of another, with ports or notches below the lip-ring seat. When the ports are closed the distribution is that of a single bell, but when the ports register with each other, or are open, the distribution is three-fold—viz., a segment of a large ring, a segment of a smaller ring, and a center heap, and as the bells make $\frac{3}{25}$ of a revolution on a vertical axis each time they close, a spiral, stratified distribution is produced. By proper manipulation a hard or a soft center can be produced at the tuyeres. Each port has a deflecting wing, and by varying the inclination, shape and angle of the same, the charge can be given any distribution required. This bell has led to 20 per cent. increase of blast-volume and 10 per cent. increase of ore-charge, giving 32 per cent. more product.

The general effect with this bell is to break up the channels, just as it is necessary to do when washing gelatinous precipitates in chemical analysis.

How gas-pressure decreases from the tuyeres upwards can be easily determined by experiment, but according to Mr. Johnson's theory, that the pressure and ascent are equally distributed over any given horizontal section, it should fall over 60 per cent. at the bosh-top of an 18-ft. furnace with an 11-ft. crucible, or to less than 6 lb. in the case he cited.

Mr. Fred H. Foote gave me a couple of pointers on "explosions" which I have never seen brought out in papers, or elsewhere, that "explosions seemed to occur with most frequency

in furnaces that were running very close on fuel, and that there appeared to be something of a warning by the appearance of that very low silicon iron, which is covered by that well-known brownish powder upon cooling, consisting mostly of carbon and silica, which can literally be seen to exude or boil out of the pigs." Explosions which began at a coke-furnace in the spring of the year continued with increasing frequency and violence until common sense suggested lightening the burden, when the trouble ceased.

Afterwards, Mr. Foote told me it was necessary to take off from 200 to 2,000 lb. from about a 16,000-lb. ore-charge in order to keep furnaces in that locality on an even keel, when the moist season came. As it sometimes occurs that furnaces burn out the center very high up, even clear to the bell, it would seem that ignition of carbon dust might be responsible for some of the "blows" that Mr. Johnson attributes simply to pockets of gas under pressure. Hanging and slips, at one time, were attributed in some cases to the furnace having worked up "too hot." I would call attention to some experience in changing from foundry to high-silicon iron, which required taking from 750 to 800 lb. of ore from an 8,750-lb. burden, leaving the charge for high-silicon iron 8,000 lb., or just a 2 to 1 burden, the coke-charge being 4,000 lb., and raising the blast-temperature from 1,000° to 1,300° F.

Now that was quite a reduction in burden, especially as the furnace was running very hot on foundry-iron, and it seems that all the conditions were provided for hanging and slipping, as the furnace appeared to be about as hot as fuel and hot blast could make it, yet slips and hanging were very rare, and, in fact, on that grade of iron were practically unknown, for which reason it has occurred to me that the theory would fit better if turned end for end—*i.e.*, that a furnace "works hot (sometimes) because it hangs" instead of "hangs because it is too hot."

The proposal to give the shaft of a furnace a more rapid taper from the stock-line down is, like the now pretty general lower and flatter bosh, a return to old charcoal-furnace lines of from 50 to 75 years ago. As the more rapid taper would naturally accompany a smaller diameter of throat, it should be an improvement, since it would force a better stock-distribution and locate the charge nearer the center, in a degree plugging

up that easy route and compelling a breaking-up of a ring of impervious fine materials, due to that most efficient device for its formation—the single charging-bell.

Mr. Uehling once stated, in a discussion, that in his opinion 90 per cent. (I believe) of all blast-furnace troubles were due to faulty charging-apparatus, and I firmly believe he did not overstate the case.

Before a slip or "blow-up" can possibly occur a cavity must be formed or burned out for the materials to slip into. The single bell always distributes the charge in the same way, usually leaving a loose center, and it burns out, if not prevented by probing and changes of blast-volume, and so the stock adheres to the walls, or it arches over, using the walls as skew-backs, and the result may finally be a slip of more or less violence. On the contrary, a furnace-charge placed well in the center is naturally more self-sustaining, and under such conditions slips less frequently.

I never saw any call for the complaints against Mesabi or other very fine ores, due to fineness, though it is probable that the extreme fineness made that impervious ring more dense, and so accentuated an already existing trouble.

For it must not be overlooked that furnaces have always slipped, and long before the Mesabi ores were discovered. Again, regarding the use of large percentages of magnetic concentrates, 35 years ago nearly or quite as fine ores were used up to 100 per cent. Mr. Bachman has used that percentage at Port Henry, and I understand has not had a slip in several years, but he uses a charging-apparatus that distributes some of the charge to the center, designed as his experience has dictated. Mr. Langdon also used as high as 90 per cent. of concentrates, I believe of greater fineness than are turned out there now, with a mixed coke-and-anthracite fuel charge, also using a center charging-apparatus. The Bay State furnaces used Cheever fine ore—a magnetite—which averaged as fine as wheat, with furnace lump anthracite coal, first as open top, hand-filled furnaces, and about 1866 they were the pioneer bell-and-hopper-charged furnaces in the United States. Their record was an enviable one, both as to fuel economy and regu- [illegible] the charging was well to the center. In [illegible] was pretty evenly distributed over a

rather narrow top, and when filled by a bell, Mr. Foote used one of 7.5 ft. diameter on a 14-ft. stock-line, which, at the present day, would be considered a small bell for so large a top. The bosh was 16 ft. and the height 66 ft.

I can cite two cases of explosions which seem to require still other explanations—a coke-furnace which slipped while the wind was off, and had been for some time, accompanied by considerable damage and great loss of life; another—an anthracite furnace—which exploded 10 hr. after lighting, and at least 20 hr. before the wind would naturally have been turned on, according to the practice at that date, lifting out the hopper and breaking both bell and hopper, besides cracking the lining down 30 ft., opening it in four places from 3 to 4 in. at the top. The real cause of the damage was neglecting to chock the bell open, and when the explosions came, the bell closed like a huge check-valve, and, as all down-comer outlets were closed, something had to yield.

The effect of moisture in the blast on the working of the blast-furnace seems to have been well understood by the oldest iron-masters. In Truran's *Manufacture of Iron*, written before Neilson's invention of the hot blast, he says, as a result of 20 years' observation of the workings of 19 blast-furnaces at Dowlais, Wales, that "there was a difference of about 16 per cent. (I speak from memory) in favor of the cold months."

Yet Mr. Robinson finds a difference of only 21 lb., or about 1 per cent., in fuel consumption for a period of ten years at the South Chicago furnaces. It is worthy of note that the Dowlais furnaces were cold-blast at that time, and Truran's observations must have begun nearly 100 years ago.

Until Mr. Richards and Mr. Johnson made their very exhaustive calculations which satisfactorily account for the saving in fuel, over and above that directly due to having less water to decompose, we were obliged to class "dry" blast with "hot" blast, the effect of which cannot be accounted for by actual calories carried in alone. In each case the first result is to concentrate the heat at the tuyere, where it belongs, which in turn sets up a secondary set of reactions, or modifies the usual ones. While it is true that a blast-temperature of 1,100° or 1,200° F. would have brought the fuel-consumption down to 1,700 lb. or thereabouts, it would seem that to cite that fact is

begging the question, as that expedient was and is open to Mr. Gayley. Supposing that circumstances had permitted Mr. Gayley to have applied dry-blast to a furnace using blast up to the highest practicable limit of heating, say from 1,800° to 2,000° F., and that the same saving had been attained over the fuel-consumption to be expected at such temperature of blast, what possible theory could have been set up to deprive dry-blast of the whole credit? The facts, as they appear at the present time, are that dry-blast was applied, and the net result was that 400 lb. of fuel were saved; a greatly increased product and greater regularity of working attained; and I believe that Mr. Gayley and "dry-blast" should receive the whole credit, no matter by what roundabout way such favorable results were obtained. It is probable that Mr. Gayley expected about what he would attain by turning summer conditions into winter ones—as he certainly would not have felt justified in spending so much money in order to save 3 or 4 per cent. in fuel-consumption, due to the less amount of water to be decomposed, and I believe he had it all carefully figured out in advance.

Mr. Johnson's "critical heat" theory seems to open up a new field for metallurgical calculations, and to explain satisfactorily many interesting and important furnace-reactions in a new and simple way. This new theory seems to amount to the self-evident proposition that that furnace which is the hottest has the greatest capacity for work in its line. Whatever the temperature may be in any given case it depends upon four factors—viz., carbon-combustion to CO, blast-temperature, humidity, and temperature of descending materials (the latter being a resultant of the other three factors, two of which are controllable within limits—blast-temperature and moisture). So, going a step further, it amounts to saying that the furnace with the most powerful stoves, and the most efficient refrigerating-apparatus, is best prepared to fulfill its office. The degree of oxidation of the top-gases may also have some effect on the temperature of materials *en route* for the tuyere region. If Mr. Johnson could have gone enough further with his calculations to have fixed a necessary amount of heat for superheating iron and slag, and doing the other things left by him for "available heat" to do, it would have been clearer to me. Now, if that

had been done or can be done, then it would appear that there would have been no "H_a" or remnant left, with economical practice, or if any, it would mark the unnecessary or surplus heat—the lack of full economy. It might also be considered as a "heat-reserve," measuring the difference between actual economy and the "dead-line," so to speak. In making calculations to determine how much slag can be made and fused per ton of carbon, I have assumed that the available heat is what is left after deducting from the total heat developed, the blast-furnace fixed charges due to that carried off by gases, radiation, cooling-appliances, expulsion of water from materials, decomposition of water in blast, etc.; though that is a different proposition, as it deals with total heat-units developed, while Mr. Johnson deals with temperature, as I understand, though I confess that I do not understand it very well. I hope and expect that a paper of such character will bring out a full and clear elucidation of so important a theory, and if it proves to be sound, Mr. Johnson will be entitled to many thanks for providing us with such a handy slide-rule for blast-furnace calculation.

Mr. Johnson's "critical heat" appears to be comparable to the "clinkering-temperature" of a rotary cement-kiln—a temperature at which chemical combination has taken place, below that of complete liquid fusion. Mr. Hilbig, of the German-American Cement Co., La Salle, Ill., places that temperature between 1,300° and 1,400° C.; taking it at 1,350° C. (or 2,462° F.), it agrees with the 2,750° given by Mr. Johnson in the case cited within 288° F., which might be sufficient to bring the materials up to "what may be conveniently called the free-running temperature of the cinder," which Mr. Johnson designates as the "critical temperature," and thus would seem to sustain the theory.

Mr. Bell was of the opinion that hydrogen had but little, if any, reducing action in the iron blast-furnace. By taking special precautions he always found it in the top-gases, and gave examples showing the amount to be from 0.84 to 1.01 per cent., calculated on the CO, or roughly, say 0.21 and 0.23 per cent. on the total gases—an amount so insignificant as to be readily lost in an ordinary gas-analysis. However, hydrogen can be qualitatively determined in the top-gases, beyond the shadow

of a doubt, without resorting to gas-analysis. In steaming a too-hot furnace to control silicon and to make "smoky" or "gray" gas burn, it was noted that a $\frac{3}{8}$-in. jet of steam at 30 lb. pressure injected into a tuyere, would show the hydrogen flame at stoves and boilers in about one minute.

Reducing the steam-pressure to the blast-pressure made the volume of steam about 1 per cent. of the blast-volume. Injecting steam for the purpose named is a very valuable expedient, and as it is required just when the furnace is too hot, there are no bad effects to fear. In case of gas blowing-engines "steaming" should be a remedy for smoky or incombustible gas. Usually steaming need not be long maintained.

Again, sometimes the only visible symptom of a leaky tuyere or cooling-device is the appearance of hydrogen in the burning gas, generally accompanied by an abnormal amount of steam.

I recall an instance where the burning gas was seen from a distance of about 3 miles issuing from the boiler and stove stacks, which were respectively 115 and 165 ft. high. Upon arriving at the furnace no signs of leaking were visible, but the leak was finally found to be from a cooling-plate about 5 ft. above the tuyeres—a $\frac{3}{8}$-in. hole and 30-ft. head of water.

Regarding the hygrometer asked for by Mr. Johnson, I would say that when I left for Mexico, 18 years ago, I had practically finished a large recording-instrument to diagram 14 different things pertaining to blast-furnace practice. Among the records to be made were the following:

Barometric pressure, air-temperature, air-humidity, revolutions of engines, pressure of blast, blast-pressure divided by blast-volume (giving resistance to passage of blast through the furnace for 1,000 cu. ft. of blast, and kept as $\frac{P}{R} = r$), temperature of blast, steam-pressure, vacuum, time lost, number of charges, time of charging, weight of elements of charges. A margin was also provided to fill in by hand the quality and grade of iron and the analysis, the whole card to be a complete furnace-journal. The recording and direct-reading hygrometer, which I may explain later, is about the simplest of the lot. The pyrometer and the instrument for dividing blast-pressure by blast-volume required the most study, but finally

were resolved into quite simple machines. A record was kept of $\frac{P}{R} = r$ for three and a half years, and it should afford some consolation to anthracite furnace-men. It showed that when two-thirds anthracite and one-third coke were used, the resistance per 1,000 cu. ft. of blast was 0.55 lb., and that when all anthracite was used the resistance was 0.77 lb. per 1,000 cu. ft.; or that it required 40 per cent. more power to blow an anthracite furnace than a one-third coke one. So when each makes its own steam, without firing boilers, the coke-anthracite furnace has more heat available for making iron. When the furnace was working normally the resistance-record was a straight line, regardless of pressure or volume, showing that the resistance was directly as the volume. When the resistance line "r" ascended or descended from the normal, it generally indicated a hotter or a cooler furnace, respectively.

The use of caustic lime, according to Bell, does not seem to promise much, if any, advantage, for the reason that at a temperature below that at which limestone gives up its CO_2, caustic lime has a strong affinity for CO_2, which would have to be again expelled lower down. I can see two other possible, though minor, disadvantages to the use of burned lime. I have had occasion to examine many samples of what was supposed to be caustic lime, but all had CO_2 in considerable quantity—from 10 to 20 per cent. and more—enough to be appreciable in fluxing where lime has to be carried to the safe limit, and probably much more burned lime would be blown out of the furnace than if raw stone were used, which would also tend to upset the fluxing-calculations.

As to the practical limit of the hot-blast temperature, I was in a position to maintain an average of 1,392° F. for more than two years, and found it a very comfortable temperature to carry, and not at all destructive to stoves or connections, providing they did not leak. Heat up to 1,700° F. was occasionally carried, and sometimes even more. For such heats the copper ball of a Siemens pyrometer was not durable, and one would show an error of 300° in a week. So platinum was substituted. For another purpose than iron-making I have just designed stoves to give from 1,000° to 1,100° C., which may be about the limit. Such high heats will require that all connections

be lined, even the belly-pipes, and also it will be necessary to wash the gas; otherwise the flue-dirt and fume will fuse and cut the walls of the combustion-chambers, and likely permanently seal up the checker-work at the top.

In the original fire-brick stoves at the Cedar Point furnace, at 1,400° F., no dust left the combustion-chambers, but all fused into cinder, and occasionally had to be dug out. A lining in belly-pipes and first elbow of tuyere-connections will cause some trouble in cleaning them, should they ever fill with slag, in which case it would be best to have spare ones at hand and clean the others at leisure. The matter of relining need not require more than from 10 to 15 minutes per tuyere, and the cost would be inconsiderable.

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

The Gas-Producer as an Auxiliary in Iron Blast-Furnace Practice.

A Discussion of the Paper of R. H. Lee.

J. T. PULLON, Rowangarth, Roundhay, Leeds, England (communication to the Secretary*):—I wish to call attention to the fact that Mr. B. H. Thwaite (who was heard here yesterday on the subject of the application of blast-furnace gas for the production of power, of which he was undoubtedly the pioneer) read, at the Engineering Congress in Glasgow in 1901, a paper on the profitable utilization of power from blast-furnace gases,[1] in which he suggested the diversion and cleaning of the whole of the waste gases coming from the blast-furnace and their utilization for power-production, so as to obtain, with proper manipulation, from 4 to 6 times the efficiency of present methods. He suggested also the heating of the stoves with producer-gas of a higher and therefore more suitable calorific value, so as to maintain them in a constant state of maximum efficiency, free from dust, and to avoid the irregular working of the furnace, besides obtaining a maximum supply of air-blast, of 15 or even 20 lb. pressure, by means of internal-combustion blast-engines driven by the cleaned waste furnace-gases, with a surplus of gas left for other uses.

Since that time, in view of the necessity of having a stand-by plant, immediately available, in case of strikes or other reasons causing the banking or blowing-out of the blast-furnace, he has developed, as an addition to his other types of producer, a high blast-pressure gas-generator, producing a gas identical with, or somewhat superior to, blast-furnace gas; and in which all the ash of the fuel is turned into fluid slag, which is available for the production of slag-wool. The gas is a little richer in carbon monoxide than average blast-furnace waste gas, and has only from 1 to 3 per cent. of hydrogen.

Fig. 1, drawn from a photograph, shows a plant containing this generator, now in operation at Leeds. It is made in units of from 1,000 to 10,000 h.p. capacity for each vessel, and coupled,

* Received September 20, 1906.

[1] *Journal of the Iron and Steel Institute*, vol. lx., No. 2, pp. 149 to 184 (1901).

of course, to Thwaite's ordinary gas-cleaning plant. It can be put in full blast in 2 or 3 hr., producing gas equal to blast-furnace gas, the most perfect of all power-gases.

The cost of the Thwaite plant is low, owing to the high pressure employed. It is automatic in its action, and the thermal efficiency is as high as practicable. There is no loss of un-

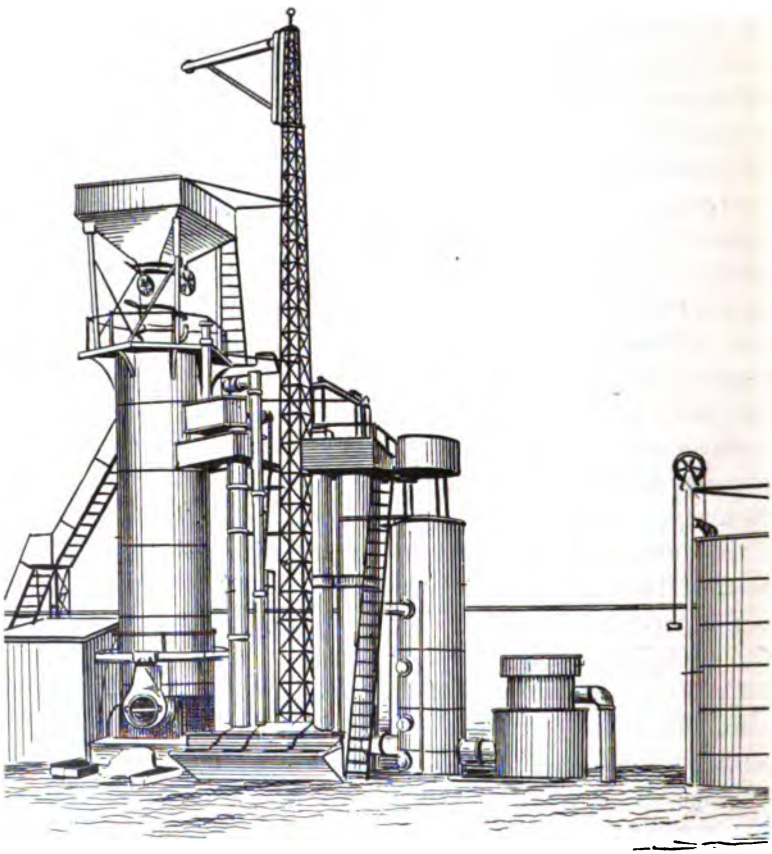

FIG. 1.—GAS-PRODUCER PLANT AT LEEDS.

burnt fuel passing out with the ash and clinker, a serious defect in other producers, especially important with those working at low temperatures. With an ordinary type of gas-engine of the comparatively small power of 100 h.p., a thermal efficiency equivalent to 8,000 B.t.u. per i.h.p. per hour has been obtained. I append two analyses of this gas, as made from ordinary gas-works coke, which contained 9.5 per cent. of ash.

Analyses of Generator-Gas.

	I. Per Cent.	II. Per Cent.
CO_2,	1.2	0.8
O,	0.4	1.8
CO,	30.0 (112.1 B.t.u.)	32.4 (110 B.t.u.)
CH_4,	0.2	0.4
H,	4.1	1.6
N,	64.1	63.0
	100.0	100.0

F. T. HAVARD, Silberhütte, Anhalt, Germany:—The utilization of waste gases from reverberatory furnaces (such as those used in the manufacture of glass, in the reduction of minerals —for instance, heavy spar—and for similar purposes) by the attachment of a producer, is already emerging from the experimental stage in Germany. It is perhaps worthy of mention that I am planning to make use of the cleaned gases from lead and copper blast-furnaces for the purpose of generating power by enriching and controlling the quality through the addition of comparatively small quantities of producer-gas of high calorific content, whereby the realization of the heat values in these gases would be effected. I cannot yet tell how these plans will succeed on a large scale, but I could not miss this opportunity to tell what the copper- and lead-smelting men are doing in utilizing the waste gases by the help of the auxiliary gas-producer.

PROF. WILLIAM KENT, Syracuse, N. Y. (communication to the Secretary*):—There are two sentences in Mr. Lee's paper which should not be allowed to pass without comment. These are:

(1) "The net calorific effect of coal burned under the boilers and in the gas-producers, respectively, is, if not the same, rather in favor of the producer; indeed, the efficiency of carbon burnt in the form of producer-gas is claimed to be from 5 to 25 per cent. greater than that of direct combustion of solid fuel."

(2) ". . . gas-producers would have the advantage over the present mode of coal firing, that a greater calorific effect is obtained from the fuel."

Solid fuel burned under boilers under proper conditions of air-supply and of heating-surface may give an efficiency of 75 per cent. or more, the remainder or loss being accounted for by heat carried away in the chimney-gases, radiation, etc. There is no way by which the use of producer-gas can diminish these chimney- and radiation-losses. In fact, the furnace under

* Received Oct. 11, 1906.

a steam-boiler is nothing but a gas-producer and a combustion-chamber combined, and nothing can be gained by separating these two parts and connecting them by a long gas-flue or main. Since the invention of the Siemens gas-producer, 50 years ago, many producers have been made to be used in connection with steam-boilers, but they have always failed in practice to show any advantage over the use of solid coal. If gas-producers have not succeeded in displacing direct firing for ordinary boilers, it is not likely they will displace coal-firing under blast-furnace boilers.

If it is necessary in blast-furnace practice to have the means of supplying a large additional quantity of heat to the steam-boilers in the case of occasional stoppage or diminution of the supply of gas from the blast-furnace, this can best be accomplished by having a very large grate-surface under the front end of the boilers and a very large combustion-chamber above the grate, for the burning both of the gases from the blast-furnace and of the gases distilled from the coal. When the gas-supply is sufficient, the ash-pit doors may be shut and the coal will not burn. When the gas-supply is diminished in quantity the ash-pit doors may be opened and the coal burned by natural draft; or if the gas is entirely shut off from one or more boilers the ash-pit doors can again be closed and the coal burned by forced draft. With a grate-surface 8 ft. long and the width of the boiler-setting in water-tube boilers, and forced draft, bituminous coal could easily be burned at the rate of 40 lb. per sq. ft. of grate per hour. This would drive the boiler from 50 to 100 per cent. above its normal rated capacity.

To provide this amount of coal-burning capacity in gas-producers would require a very expensive producer-plant without any gain in economy over the coal-firing. A good plan for a water-tube boiler-setting for blast-furnaces is the one designed by Mr. Julian Kennedy for the Lucy blast-furnace.[2]

For the purpose of increasing the grate-surface under this boiler, I would modify that design by moving the gas-flue, gas-burner and front wall of the boiler-setting and the perforated wall outward 4 ft. in front of the present position, forming thus a gas-combustion chamber in front of the boiler-setting, which would leave room for a grate-surface nearly 8 ft. wide, thus doubling the coal-burning capacity of the grate.

[2] *Trans.*, xiii., 46 (1884–85).

[TRANSACTIONS OF THE AMERICAN INSTITUTE OF MINING ENGINEERS.]

Proceedings of the Ninety-Second Meeting, New York, N. Y., April, 1907.

THIS meeting was held in the new home of the Institute, the United Engineering Society Building, 29 West 39th Street, New York City, directly following the Dedication ceremonies.

The first session was held in the large Auditorium, Thursday, April 18.

The meeting was called to order by Mr. John Hays Hammond, President of the Council, who said:

Before taking up the reading and discussion of papers, I will call upon Dr. Rossiter W. Raymond, the oldest living past-President of the Institute, who has been in harness almost continuously for thirty-six years, and who has contributed more than any one else to bring this society to its present great success and to establish the reputation of the American mining engineer the world over, for a few words supplementary to those which were uttered to engineers generally, during the sessions of yesterday and the day before.

ADDRESS BY R. W. RAYMOND.

The generally accepted Darwinian doctrine of the survival of the fittest is sometimes illustrated by persons who are supposed to be the fittest because they have simply survived. I fear that I come under that category. Almost all of my contemporaries in the early history of this Institute have passed away. Only one or two of the original founders remain, and I may fairly say that scarcely any remain who were active at that time in shaping the organization and the future career of the Institute.

In May, 1871, I was thirty-one years old. Next week I shall be sixty-seven years old. All the intervening years have been devoted to the service of this Institute almost continuously, either as President or Vice-President or Secretary. You may easily imagine, therefore, with what pleasure I greet you on this occasion.

I am not here to extend to you the welcome of the City of

New York. We have met here over and over again; and we have always had a Mayor or some other public functionary to extend to us, as guests of the City, its hospitalities and courtesies. You will never be thus welcomed to New York again, for it is now your home. You enter this day, for the first time, the place that belongs to you. For more than thirty years the Institute was not incorporated, or located anywhere. The very nature of our society was such that we could not without peril to its future tie it specially to any one locality. Comprising as it did a membership most widely distributed, both geographically and professionally, it had no more right to exist in one place than in another; and an attempt to place it at one spot would simply have been a signal for the appearance of other local societies in other spots. This is not the time and place to go into a long history of that critical question; but I may say that there was a time when this Institute ought to have been located, if anywhere, in Philadelphia. To the present day, Pennsylvania is far more distinctly a mining State than New York. There was a time when there was danger of the establishment of some rival Institute in the West. There have been times when it was very plausibly proposed to start other national societies, especially for iron and steel and coal. Through all that period the Institute, by being peripatetic, kept itself national. Its office was first at Lambertville, New Jersey, where the first Secretary, the late Martin Coryell, happened to reside. When Dr. Thomas M. Drown became the Secretary, the headquarters went to Philadelphia, without any vote on the part of the members or the Council, simply because the Secretary lived in Philadelphia. When Dr. Drown became a Professor in Lafayette College, the Institute, in similar informal fashion, went to Easton; and when I succeeded Dr. Drown, the Institute came to my office in New York. For many years, the Institute never owned so much as a chair; it was in my private office that its business was done. Headquarters could have been moved, or, rather, would have moved themselves, at any time, if the wholesome and brilliant thought had ever struck you to choose another Secretary.

The munificence of Mr. Carnegie, extended when the lapse of time had shown the true intent and purpose of the Institute and allayed once for all every possible local prejudice or am-

bition, made it possible for us to join in the movement which has ended in the acceptance and occupation of this splendid building. To do that, it was necessary that we ourselves should be incorporated, and that another corporation should be formed, to hold and administer the building in which we were to become tenants. "United Engineering Society" is not strictly a society at all. It is simply a Board of nine eminent and trustworthy Trustees, elected (three from each of the "Founder Societies") to hold and administer this building. I need not characterize its legal title as an unfortunate misnomer, unless it should lead to embarrassing misapprehension on the part of foreigners, through the inference on their part that a new society, constituting an organic union, has come into existence.

We Americans know very well that our three societies are the same old organizations, and have joined in the creation of this business board, simply to take care of the real estate represented in this building. We occupy our several quarters in the building in a spirit of absolutely free and voluntary fraternity, without any superior authority over us; without any limitation of our organization, or our purposes, or our methods; and without any submission to outside control.

I deem it important to say this, because our Institute has always differed from the two sister societies in the character of its organization, in the wider distribution and less stringent requirements of its membership, in the practical omnipotence of its governing body, and in the limitation of that absolute power to definite purposes, excluding all action or utterance whatever, in support of any theory, movement, enterprise or purpose, outside of the holding of our meetings and the publication of our proceedings. We are a free forum for information and discussion. We never allow any committee of ours to come to any conclusion that we must adopt. Thus, in many respects, we stand on our own platform, pursue our own purposes by our own methods, recognizing, meanwhile, that the more select societies such as those of the Mechanical Engineers and the Electrical Engineers, which have sprung from our loins, have methods and systems of their own which are doubtless best for them. I wish the members of the Institute from all parts of the country to recognize once for all that we have sacrificed nothing of our individuality or autonomy by this new close and cordial fraternal union.

Moreover, I desire to express for our Institute (not, of course, attempting to speak for the others, though confident of their assent), the feeling that, in the numerous formalities and crowded proceedings of the recent Dedication, certain acknowledgments were omitted, which, so far as we are concerned, we wish to supply. We desire to put on record our thanks, by name, to the members of the Conference and Building committees who did our work on those committees. I have no doubt the other societies will take the opportunity to make similar acknowledgments; and I do not now extend thanks to any of their members, because it is their business to do it!

Yet, from Messrs. Charles Wallace Hunt and John W. Lieb, Jr., down, the members of those committees were altogether too modest in the dedication exercises. They did not give us a chance to blow their trumpets, and they did not blow their own trumpets, and consequently the men that did the most have had, so far, very little recognition. As Secretary of the Institute and intimately acquainted, though not personally concerned, with the progress of all this delicate, difficult and complicated work, I wish to emphasize the names of our three representative members for the most of the time—Dr. A. R. Ledoux, Mr. Charles Kirchhoff and Mr. Theodore Dwight.

And I wish to emphasize still more strongly a name that has not been heard on this platform, I regret to say, since the dedication exercises began. When, from numerous anonymously offered designs, our Building Committee had selected, with a unanimity amounting almost to inspiration, the plans for this building, they found that the names signed thereto were those of Mr. Herbert D. Hale and his associate, Mr. Henry G. Morse. Mr. Hale, as I am informed, has been absent from all these exercises by reason of illness. Nobody that ever met him can doubt the brilliancy of his genius and the breadth of his culture; and we recognize the permanent stamp of both in the design and details of this edifice.

Mr. Morse, the son of an eminent and beloved member of the American Institute of Mining Engineers, assumed in this case more than the duties of a clerk of works or an inspector. Mr. Morse practically camped on this building; he spent his days and nights here; he scarcely forsook it during

the whole period of its erection; and, without the least disparagement of the great genius of his brilliant associate and chief, Mr. Hale, I say it is due to Henry G. Morse more than to any other man that the record of this building is thoroughly creditable to us all as engineers. For engineers must not only *plan* things, but also *do* things. Now, we do not have to blush for a building which was not completed on time, or cost more than the money provided, or the detailed specifications for which were not always ready when wanted, so that the contractor had the opportunity to make extra charges for errors, changes and delays. Any of you who have had to do with the erection of buildings know what that means. All such delays, corrections and afterthoughts, warranting the claim of extra pay by the contracting builder, are merely so many evidences of somebody's lack of forethought, or somebody's lack of promptness and fidelity. The record of this building is as clean as its walls. It was built as it was designed. Not an error in its plan has had to be corrected. In spite of a couple of those exhibitions of irresponsible tyranny known as sympathetic strikes, it was completed practically on time; and it was built with the money provided. Engineers can hold up their heads with pride in the thought that, somehow or other, through somebody's fidelity, this result was achieved. I would distribute the praise for it down through United Engineering Society and its Building Committee; but they will all heartily agree with me in naming, as chief of all these hearty co-laborers, Mr. Henry G. Morse. The stainless record of this construction is mainly due to him. Mr. Morse personally tapped every rivet, in every plate or beam of this building. If anything had been covered up he had it uncovered; and hundreds of rivets, which did not satisfy his stringent tests, were taken out and replaced. In this and in many other particulars, his enthusiastic, unselfish and efficient co-operation went far beyond his legal duties and obligations; and we owe it largely to him that the erection of this classic and stately, yet simple and thoroughly suitable structure was a masterpiece worthily crowning its design.

I am requested also to call attention to certain details which Mr. Olcott, past-President of this Institute and now President of United Engineering Society, accidentally omitted to mention day before yesterday, in his remarks acknowledging the

reception of the key to this building. Yesterday afternoon, the President of our Council, Prof. John Hays Hammond, in a few fitting words, emphasized the priority of the mining engineer as the pioneer of all engineering progress. I would now emphasize not only that general leadership, but also, as regards the history which culminates in this occasion, the seniority of our Institute. The American Institute of Mining Engineers

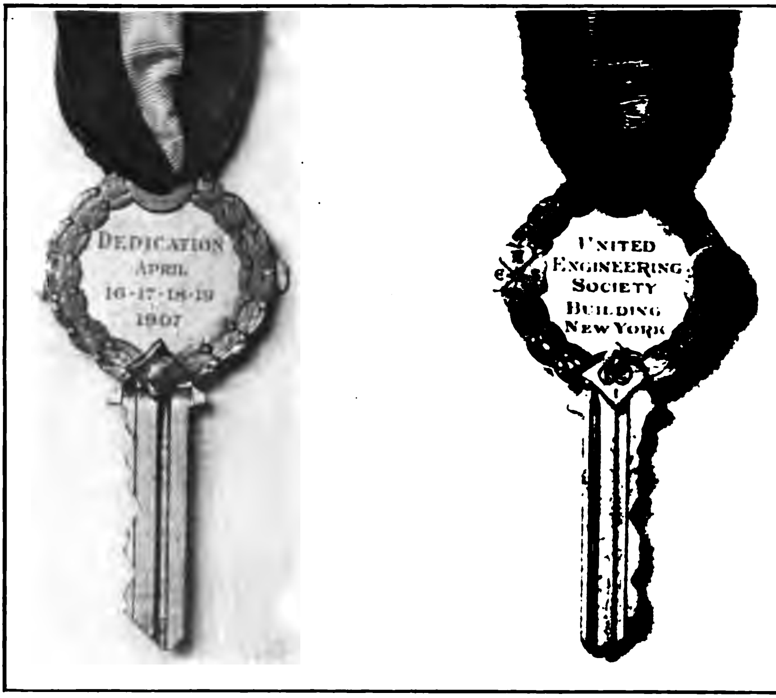

FIG. 1.—THE GOLD KEY OF THE UNITED ENGINEERING SOCIETY BUILDING.

is practically the parent of the other two Founder Societies now nestling by its side. Twice we went to sleep, and when we woke up we missed a rib—and there was another society!

This key, Fig. 1, fitly recognizes our primacy. The handle is of gold from the North Star mine at Grass Valley, California, which many of you have visited, and the President of which has been, for many years, Mr. James D. Hague, now Vice-President of the Council of the Institute, who kindly provided

the metal for this purpose. It bears upon one side the three symbols representing the seals of the three societies. So far, it sets forth, as it ought to do, their good fellowship and brotherhood, uttered, however, in terms of the mining engineer, namely, in gold, with which the electrical and mechanical engineers have much less to do than we. But on the other side is the frank admission of that primacy upon which we never insist, unless it is by silence or contradiction implicitly denied. For there, in a little frame, covered with a bit of rock crystal from the "Mother Lode," are two or three grains of the very gold washed by Marshall in 1848 from the waters of Sutter creek, in California.

We owe not only the gift of these historic souvenirs, but also the documentary proof of their authenticity, to Mr. George F. Kunz, a New York member of the Institute.

It may interest you to hear that, many years after the great discovery, President Hammond went to the same spot with Marshall, who was his good friend, and panned out some more gold. So, you see, the American Institute of Mining Engineers is directly connected with the epoch-making event which led to the conquest of a continent, and the inauguration of a new industrial age. Whoever, therefore, shall hereafter open the door of this building will acknowledge thereby the fraternal leadership of the American Institute of Mining Engineers!

Comrades! as your servant and fellow, I welcome you to your own house. If I should live to be a hundred years old instead of sixty-seven, my last hour of intelligent effort will be given to the service of the American mining engineers. If I should die to-morrow, I shall have lived a happy life in that service!

The following paper, illustrated by lantern-views, was presented in oral abstract by the author:

Mining Operations in New York City and Vicinity, by H. T. Hildage, New York, N. Y.*

The second and concluding session was held Friday, April 19, at 2.30 p.m., in the large lecture-room, President Hammond presiding.

* Published in *Bi-Monthly Bulletin*, No. 15, May, 1907.

The following papers were presented in oral abstract by the authors:

The Influence of the Conditions of Casting on Piping and Segregation as Shown by Wax Ingots, by H. M. Howe and Bradley Stoughton, New York, N. Y.* (Discussed by Robert W. Hunt, Chicago, Ill.)

The White Knob Copper-Deposits, by James F. Kemp, New York, N. Y., and C. G. Gunther, Clifton, Ariz.†

Laboratory Experiments in Lime-Roasting a Galena Concentrate with Reference to the Savelsberg Process, by H. O. Hofman, R. P. Reynolds and A. E. Wells, Boston, Mass.‡ (Prof. Hofman in the absence of the author read, in oral abstract, and replied to the discussion of his paper, by George A. Packard, Rolla, Mo.*)

Discussion of Paper of Mr. Meissner, Notes on the Gayley Dry-Air Blast, by J. E. Johnson, Jr., Glen Wilton, Va.* (Discussed by Mr. Meissner, Prof. Howe and Mr. Johnson.*)

The following papers were presented in printed form:

Grinding in Tube-Mills at the Waihi Gold-Mine, Waihi, New Zealand, by E. G. Banks, Waihi, New Zealand.‡

The Butters Slime-Filter at the Cyanide Plant of the Combination Mines Company, Goldfield, Nev., by Mark R. Lamb, Goldfield, Nev.‡

Fluorite and Barite in Tennessee, by Thomas L. Watson, Blacksburg, Va.‡

Geology of the Exposed Treasure Lode, Mojave, Cal., by Courtenay De Kalb, Los Angeles, Cal.‡

Deutschman's Cave, near Banff, B. C., Canada, by W. S. Ayres, Banff, Alberta.‡

The Constitution of Ferro-Cuprous Sulphides, by H. O. Hofman, W. S. Caypless and E. E. Harrington, Boston, Mass.‡

The Roasting of the Argentiferous Cobalt-Nickel Arsenides of Temiskaming, Ontario, Canada, by H. M. Howe, New York, N. Y.; William Campbell, New York, N. Y.; and C. W. Knight, Cobalt, Ontario, Canada.‡

Relative Elimination of Iron, Sulphur, and Arsenic in Bessemerizing Copper-Mattes, by E. P. Mathewson, Anaconda, Mont.‡

* To be published in *Bi-Monthly Bulletin*, No. 16, July, 1907.

† Published in *Bi-Monthly Bulletin*, No. 14, March, 1907.

‡ Published in *Bi-Monthly Bulletin*, No. 13, January, 1907.

Piping and Segregation in Steel Ingots, by H. M. Howe, New York, N. Y.*

An Early Instance of Blowing-In without "Scaffolding Down," by Frank Firmstone, Easton, Pa.*

The Extraordinary Faulting at the Berlin Mine, Nevada, by Ellsworth Daggett, Salt Lake City, Utah.*

The Ore-Deposits of the Joplin Region, Missouri, by F. L. Clerc, Denver, Colo.*

A Study in Refining and Overpoling Electrolytic Copper, by H. O. Hofman, R. Hayden and H. B. Hallowell, Boston, Mass.*

The Formation and Enrichment of Ore-Bearing Veins, by George J. Bancroft, Denver, Col.†

Search for the Causes of Injury to Vegetation in an Urban Villa near a Large Industrial Establishment, by Persifor Frazer, Philadelphia, Pa.†

Bibliography of Injuries to Vegetation by Furnace-Gases, by Persifor Frazer, Philadelphia, Pa.†

The Velocity of Galena and Quartz Falling in Water, by Robert H. Richards, Boston, Mass.†

Discussion of Paper of Messrs. Gibb and Philp, The Constitution of Mattes Produced in Copper-Smelting, by Allan Gibb, Queensland, Australia.‡

Discussion of Paper of Mr. Read, The Secondary Enrichment of Copper-Iron Sulphides, by Eugene C. Sullivan, Washington, D. C., and Reply by T. T. Read, Colorado Springs, Colo.‡

Discussion of Paper of Mr. Colby, Comparison of American and Foreign Rail-Specifications, with a Proposed Standard Specification to Cover American Rails Rolled for Export, by E. Windsor Richards, London, England; R. Price-Williams, London, England; F. W. Harbord, London, England; R. A. Hadfield, London, England; J. E. Stead, Middlesbrough, England; James E. York, New York, N. Y.; A. Lamberton, Sheffield, England; Robert W. Hunt, Chicago, Ill.; E. F. Kenney, Philadelphia, Pa.; W. E. Freir, London, England; William R. Webster, Philadelphia, Pa.; C. S. R. Palmer, London, England; Albert Sauveur, Cambridge, Mass.; M. Nigond, Paris, France;‡ and Reply by Albert Ladd Colby, New York, N. Y.*

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* Published in *Bi-Monthly Bulletin*, No. 14, March, 1907.

† Published in *Bi-Monthly Bulletin*, No. 15, May, 1907.

‡ Published in *Bi-Monthly Bulletin*, No. 13, January, 1907.

Discussion of Papers of Messrs. Hubert, Westgarth and Reinhardt on Gas-Engine Practice, by Adolph Greiner, Seraing, Belgium; Tom Westgarth, Middlesbrough, England; Julian Kennedy, Pittsburg, Pa.; R. W. Raymond, New York, N. Y.; William Kent, Syracuse, N. Y.; E. J. Duff, Liverpool, England; James Hamilton, Coatbridge, England; A. T. Tannett-Walker, Leeds, England; Mark Robinson, London, England; Professor Turner, Birmingham, England; and B. H. Thwaite, London, England.*

Discussion of Paper of Mr. York, Improvements in Rolling Iron and Steel, by R. W. Hunt, Chicago, Ill., and Kurt Kerlen, Düsseldorf, Germany.*

Discussion of Paper of Mr. Grammer, Flue-Dirt and Top-Pressure in Iron Blast-Furnaces: a Study of the Influences Controlling Them, and the Paper of Mr. Johnson, Physical Action of the Blast-Furnace, by T. F. Witherbee, Durango, Mexico.†

Discussion of Paper of Mr. Corson, Heat-Treatment of Steels Containing Fifty Hundredths and Eighty Hundredths Per Cent. of Carbon, by Albert Sauveur, Cambridge, Mass.*

Discussion of Paper of Messrs. Hofman, Reynolds and Wells, Laboratory Experiments in Lime-Roasting a Galena Concentrate, by George A. Packard, Rolla, Mo.‡

Discussion of Paper of Mr. Lee, The Gas-Producer as an Auxiliary in Iron Blast-Furnace Practice, by J. T. Pullon, Leeds, England; F. T. Havard, Anhalt, Germany; and William Kent, Syracuse, N. Y.†

The following papers were presented in manuscript:

The Occurrence and Effects of Zinc in the Iron Blast-Furnace, by John J. Porter, Staunton, Va.

Barium Sulphate Associated with Iron-Ore Found in the Pinar del Rio Province of Cuba, by Charles Catlett, Staunton, Va.

On the Presence of Gold and Silver in Deep-Sea Dredging, by Luther Wagoner, San Francisco, Cal.

The White Marble Industry of Alabama, by Richard Peters, Jr., Talladega, Ala.

* Published in *Bi-Monthly Bulletin*, No. 13, January, 1907.

† Published in *Bi-Monthly Bulletin*, No. 15, May, 1907.

‡ To be published in *Bi-Monthly Bulletin*, No. 16, July, 1907.

Some Australasian Tin-Deposits, by William R. Rumbold, Oruro, Bolivia, South America.

The Vein-System of the Standard Mine, Bodie, Cal., by R. Gilman Brown, San Francisco, Cal.

The Law of Fissures, by Blamey Stevens, Ellamar, Alaska.

The South-African Tin-Deposits, by William R. Rumbold, Oruro, Bolivia, South America.

Tables for the Calculation of Microscopic or Geometric Analyses of Rocks, by James Underhill, Idaho Springs, Colo.

Laboratory-Tests in Connection with the Chlorination Process, by A. L. Sweetser, Cananea, Sonora, Mex.

The Physical Metallurgy of the Reduction of Zinc Oxide, by Woolsey McA. Johnson, Hartford, Conn.

The Verschoyle Pocket Transit, by W. D. Verschoyle, Ballisodare, Ireland.

The Panoramic Camera Applied to Photo-Topographic Work, by Charles W. Wright, Washington, D. C.

Biographical Notice of Thomas S. Austin, by L. S. Austin, Houghton, Mich.

Biographical Notice of William G. Neilson, by John Birkinbine, Philadelphia, Pa.

Notes on the Present Source and Uses of Vanadium, by J. Kent Smith, Pittsburg, Pa.

The Calumet and Arizona Smelter at Douglas, Ariz., by Herman O. Schulze, Wonder, Nev.

Discussion of Paper of Mr. Read, The Secondary Enrichment of Copper-Iron Sulphides, by A. H. Allen.

Discussion of Paper of Mr. Mathewson, Relative Elimination of Iron, Sulphur, and Arsenic in Bessemerizing Copper-Mattes, by H. M. Howe, New York, N. Y.

Discussion of Paper of Mr. Howe, Piping and Segregation in Steel Ingots, by F. Beutter, Paris, France.

The following papers were read by title:

The Origin of the Iron-Ores of Scandinavia, by Hjalmar Sjögren, Stockholm, Sweden.

Gas-Producer Power-Plant, by S. S. Wyer, Columbus, Ohio.

The Gold-Belt of the Eastern Part of North Carolina, by W. O. Crosby, Boston, Mass.

Excursions and Entertainments.

In addition to the Dedication exercises of the United Engineering Society Building, Tuesday and Wednesday, April 16 and 17, and the accompanying reception, Tuesday evening, April 16, members and guests of the Institute were cordially invited to attend a meeting of the American Institute of Electrical Engineers on Monday evening, April 15, at which Mr. Louis M. Potts presented his paper, The Rowland Telegraph System and Its Apparatus.

A similar invitation was extended by the American Society of Mechanical Engineers for Thursday evening, April 18, to hear Brig.-General William Crozier deliver his address, The Ordnance Department as an Engineering Organization. Both of these meetings were held in the large Auditorium of the United Engineering Society Building.

On Friday evening, April 19, an informal smoker and vaudeville entertainment was given at the Concert Hall, Madison Square Garden, under the auspices of the American Institute of Mining Engineers, the American Society of Mechanical Engineers, and the American Institute of Electrical Engineers. At the conclusion of the interesting program a collation was served to the members and guests present, amounting to about 400 in number. The details of the smoker were in charge of Mr. Theodore Dwight.

On Saturday morning, April 20, through the courtesy of Mr. Alfred Noble and Mr. C. M. Jacobs, Chief Engineers of the Pa., N. Y., & L. I. R.R. Co., visits were made to portions of the tunnel-work described in the paper of Mr. H. T. Hildage.*

A party of about 30 met at 33d street and Seventh avenue, New York City, and inspected the enormous excavation that is being made for the great terminal station. Two divisions were then formed, one for the work of the Hudson River and one for the work of the East River. The former party, under the charge of Mr. Jacobs, proceeded by launch to Weehawken and visited the shaft and tunnels at Bergen Hill, going thence to the shops of the company to see the brass working-model of a modern shield and a model of the tunnel, to be exhibited at the Jamestown Exposition. At 15th street, Jersey City, the

* See page 461.

so-called "old" Hudson River tunnel was entered and the walk under the Hudson River to Manhattan Island begun. The tunnel was brightly lighted by electric lights throughout. After reaching Morton street and still underground a visit was made to the Christopher street section, where the 50-ft. reinforced-concrete arch in quicksand for a cross-over was inspected. This work is carried on at an air-pressure of from 8 to 9 lb. per sq. in. above the normal. The interesting and enjoyable visit terminated with a luncheon at the Engineers' Club through the courtesy of the Local Committee.

The party in charge of Mr. Noble proceeded to the compressor-plant at 33d Street and East River, which is the largest plant for this class of work in the world. Later, the tunnel-work at East avenue, Long Island City, was visited, and much interest was shown in the operation of a full-sized working shield that had been set up above ground for the purpose of illustrating the manner in which the shield is pushed ahead.

Members and Guests Registered at New York.

The following list, which in all probability does not include the names of all who attended the sessions and excursions, comprises the names of members and guests registered at headquarters.

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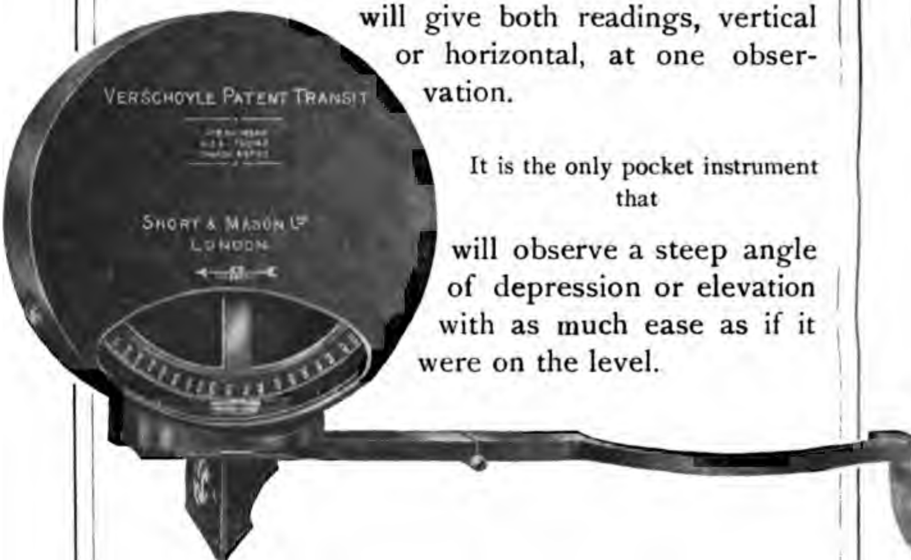

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